PB-242 287

WATER POLLUTION INVESTIGATION: MAUMEE RIVER AND TOLEGO AREA

J. Horowitz, et al

Environmental Control, Incorporated

Prepared for:

Environmental Protection Agency

January 1975

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

163050

PB242287

EPA-905/9-74-018

WATER POLLUTION INVESTIGATION: MAUMEE RIVER AND TOLEDO AREA

ENVIRO - CONTROL INC

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V ENFORCEMENT DIVISION
GREAT LAKES INITIATIVE CONTRACT PROGRAM

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield, VA. 22151

JANUARY 1975

BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA-905/9-74-018

2\.

PB 242 287

4. Title and Subtitle
Water Pollution Investigation: Maumee River and Toledo Area

5. Report Date
January 1975

6\.

7. Author(s)
J. Horowitz, J. R. Adams, and L. A. Bazel

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Enviro-Control, Inc.
960 Thompson Avenue
Rockville, Maryland 20852

10. Project/Task/Work Unit No.

11. Contract/Grant No.
EPA Contract No.
68-01-1567

12. Sponsoring Organization Name and Address
U. S. Environmental Protection Agency
Enforcement Division, Region V
230 S. Dearborn St.
Chicago, Illinois 60604 EPA Project Officer: Howard Zar

13. Type of Report & Period Covered
Final Report

14\.

15. Supplementary Notes Additional support from the Toledo Metropolitan Area Council of Governments, H. B. Russelman, Water Quality Project Director under a U.S. Environmental Protection Agency Section 208 Grant (No. P00515101).

16. Abstracts

The combination of long retention times in the Maumee estuary, large rural sources of landwash, sludge beds below river mile 6, poor sewerage, a large cooling-water discharge from the Acme powerplant, and the erratic performance of Toledo's sewage treatment plant has degraded the lower Maumee River; several nearby streams are heavily polluted. These waters are loaded with solids, they are enriched with nutrients and organics, and they violate Ohio's oxygen and bacterial standards. Even if Toledo were to be wiped off the map, these conditions would not entirely disappear, nor would many of them be much changed.

17. Key Words and Document Analysis. 17a. Descriptors

Water Quality, Water Pollution

17b. Identifiers/Open-Ended Terms

Toledo Area, Maumee River, Lake Erie, Great Lakes, Chemical Parameters

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page UNCLASSIFIED

21. No. of Pages 183

22. Price 7 00

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952

WATER POLLUTION INVESTIGATION: MAUMEE RIVER AND TOLEDO AREA

by

J. Horowitz - Enviro-Control, Inc.

J. R. Adams - Toledo Metropolitan Area Council of Governments

L. A. Bazel - Enviro-Control, Inc.

In fulfillment of

EPA Contract No. 68-01-1567*

for the

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V

Great Lakes Initiative Contract Program
Report Number: EPA-905/9-74-018

EPA Project Officer: Howard Zar

January 1975

* Additional Support Provided by

The Toledo Metropolitan Area Council of Governments

under U.S. EPA Section 208

Grant No. P00515101

This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provisions of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

This report has been reviewed by the Enforcement Division, Region V, Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The combination of long retention times in the Maumee estuary, large rural sources of landwash, sludge beds below river mile 6, poor sewerage, a large cooling-water discharge from the Acme powerplant, and the erratic performance of Toledo's sewage treatment plant has degraded the lower Maumee River; several nearby streams are heavily polluted. These waters are loaded with solids, they are enriched with nutrients and organics, and they violate Ohio's oxygen and bacterial standards. Even if Toledo were to be wiped off the map, these conditions would not entirely disappear, nor would many of them be much changed.

* * *

> La plupart de ceux qui souffrent connaissent le remède à leur mal. Et le monde, autour d'eux, lui aussi connaît ce remède. Et cependant de toute cette connaissance rien ne naît pour leur soulagement.
>
> (Henry de Montherlant, Les Célibataires.)

PREFACE

This study of water quality and pollution problems in the Toledo area was principally funded by Region V of the U. S. Environmental Protection Agency, under contract 68-01-1567; the Toledo Metropolitan Area Council of Governments supported the field work in September 1974 with funds from a U. S. EPA section 208 grant.

We are greatly indebted to many public agencies and private individuals whose generosity and helpfulness went far beyond the customary civilities and professional courtesies. It is a pleasure to be able to thank them by name. Howard L. Cook[1], our valued friend, went over our data to help us achieve some understanding of the Maumee estuary's perplexing hydraulic behavior and poised complexities. John E. Kinney[2] was an inexhaustible reservoir of practical suggestions for our sampling program, an insightful critic of our draft report, and a dynamo of ideas for data analysis. William C. Beckett[3] opened his personal library of historical materials on the Toledo area to us, and unfailingly answered our questions on commercial activities, place names, and miscellaneous Protestant Toledianawith accuracy, good humor, and staggering erudition. Peter C. Fraleigh[4] gave without reservation of his technical insights, kindly lent us equipment for our springtime sampling survey, helped recruit a field team, prepared a valuable critique of our draft report, and did all this with such enthusiasm, cordiality, and welcoming high spirits as one rarely encounters.

The Columbus District Office of the U. S. Geological Survey deserves a very special word of thanks for their helping us in every way they could, on extremely short notice, in both May and September 1974. They ensured that the Waterville gage was in perfect working order during both surveys, and that its records were promptly delivered to us. They sent out field teams to take measurements (lake effects, river velocity, discharge) on both occasions, even though this meant working over at least one weekend. We are especially grateful to Peter Anttila, Eddie Wilson, Mike Smith, George Gravlee, James Blakey, and Arthur Westfall.

---

[1] Consulting hydrologist and hydraulic engineer, Washington, D.C. Formerly with the USDA and the Corps of Engineers.

[2] Sanitary Engineering Consultant, Ann Arbor, Michigan.

[3] Manager of Statistics, Toledo-Lucas County Port Authority.

[4] Department of Biology, University of Toledo.

We were fortunate far beyond reasonable expectation in our field crews. For industry, willingness, resourcefulness, and cheerfulness in adversity, there can be few men to equal William A. Tank, Sr., William A. Tank, Jr., and Martin L. Tank; nor can the Tank family have many rivals in knowing the waters in and around Toledo. James G. Bennett of Toledo Caisson came to our rescue in more than one way; we shall never forget his making emergency repairs on a Kemmerer sampler late one Friday night. Russ Gorsha and his outstanding staff at Bowser-Morner's Toledo office were all one could hope for in a sediment-sampling crew. Kenneth Frank, Dennis Strahm, and Ellen Russell, biology students at the University of Toledo, were willing hands.

Leon Pfouts, Thomas Kovacic, Robert Davis, and Richard Uscilowski of the Toledo Pollution Control Agency were always hospitable and helpful, even when we had unpleasant observations about TPCA's own program of stream surveys. Robert Imo, Chief Chemist at the Toledo STP until late September 1974, eased our work in dozens of small ways, and always made us welcome; we are also grateful to Mrs. Helen Imo, Chief Chemist at the Maumee STP, for opening her files and her laboratory to us. George Garrett of the Ohio EPA (Columbus office) kindly supplied details about the State surveys of the Maumee which were published in 1953 and 1966; Robert Reitz, Cliff Merritt, James Orlemann, and John Harris of OEPA's Bowling Green office were candid and helpful informants.

"Gratitude" does not encompass our debt to Fred W. Doering, Analytical Chemist at the Jones & Henry Laboratories, Toledo. Together with his colleagues (Gayle Barnes, Linda Sneddon, and Norman Huff), he did more than ensure that our water and sediment samples were promptly, carefully analyzed: Any doubts we had about any of the results were resolved, not by rationalization, but by reanalyzing the samples, sometimes five or six times in as many ways, to guarantee that the values we report here are true, free from quirks and idiosyncracies. If samples had to be received at midnight, they were, and the analyses were begun immediately, with good cheer. No time was too late, no schedule was too tight: No words can express our thanks.

We gratefully acknowledge the hospitality of the Maumee River Yacht Club and of the U. S. Coast Guard's Toledo Station: Both kindly allowed us free dockage when none could be bought. Ken Powell of the Corps of Engineers Toledo Field Office went out of his way to answer our questions about the stage-height recorder at the mouth of the Maumee, and to send us its records promptly.

Above all, we wish to thank the many people of the Toledo area who suffered our persistent inquiries, helped us find our way around, and treated us with uncommon courtesy. We pray that this report may be of some small service to them.

We are much indebted to several of our colleagues at Enviro Control: to J. D. Morton, P. M. Sprey, N. A. Eisenberg, and A. F. Hadermann for their astute observations and technical suggestions; to C. W. Summers for easing every administrative burden; and especially to Judy Breidenbaugh, Annelle Crandall, Cathy Steele, and Elizabeth Unger for their skillful secretarial help.

J. H.
Rockville, Maryland
December 1974

CONTENTS

Page

ABSTRACT i

PREFACE ii

FIGURES vi

TABLES vii

Section

1. CONCLUSIONS 1
2. BACKGROUND AND DESCRIPTION OF THE AREA 15
3. WATER QUALITY STANDARDS (WQS) IN THE TOLEDO AREA 22
4. SURVEILLANCE 28
5. TOLEDO'S SEWERS AND THE NEW STP 41
6. AREA SOURCES AND THE UPRIVER HERITAGE 51
7. RIVER SAMPLING 63
8. SEDIMENT SAMPLING 119
9. ANALYTICAL METHODS 125
10. RECOMMENDATIONS 129

APPENDIX 1. Dissolved Oxygen, Temperature, and Conductivity in the Maumee River Estuary, 21-25 September 1974 133

APPENDIX 2. Miscellaneous Observations on the Maumee River and Nearby Streams 162

FIGURES

Number		Page
1-1	Flow and Sediment Loads at Waterville (USGS #04193500): October 1966 - March 1967	6
1-2	Lower Maumee River Site Map	13
1-3	Toledo Site Location Map	14
6-1	Flow and Sediment Loads at Waterville (USGS #04193500): October 1969 - March 1970	53
7-1	Waterville Hydrograph, 27 April - 23 May 1974	64
7-2	Waterville Hydrograph, September 1974	65
7-3	Stage Heights at Mouth of Maumee, 8 May 1974	66
7-4	Stage Heights at Mouth of Maumee, 9 May 1974	67
7-5	Stage Heights at Mouth of Maumee, 10 May 1974	68
7-6	Stage Heights at Mouth of Maumee, 11 May 1974	69
7-7	Stage Heights at Mouth of Maumee, 12 May 1974	70
7-8	Stage Heights at Mouth of Maumee, 18 September 1974	71
7-9	Stage Heights at Mouth of Maumee, 19 September 1974	72
7-10	Stage Heights at Mouth of Maumee, 20 September 1974	73
7-11	Stage Heights at Mouth of Maumee, 21 September 1974	74
7-12	Stage Heights at Mouth of Maumee, 22 September 1974	75
7-13	Stage Heights at Mouth of Maumee, 23 September 1974	76
7-14	Stage Heights at Mouth of Maumee, 24 September 1974	77
7-15	Stage Heights at Mouth of Maumee, 25 September 1974	78
7-16	Stage Heights of Lake Erie at Buffalo, N.Y., 24 September 1974	79
7-17	Stage Heights of Lake Erie at Buffalo, N.Y., 25 September 1974	80
7-18	Maumee River Transects	83
7-19	14°-BOD and 20°-BOD Rate Curves: Maumee River, 10-12 May 1974	111
7-20	20°-BOD Rate Curves, Maumee River, 20-25 September 1974	115

TABLES

Number		Page
1-1	The Upstream Heritage and Area-Source Effects: The Maumee River at Perrysburg Bridge on 10-11 May 1974 and on 20 September 1974	7
1-2	Pollutant Concentrations at Mid-Mouth (Mid-Depth) in the Maumee River, 12 May 1974 and 25 September 1974	11
5-1	Toledo STP Data: 5-12 May 1974	48
5-2	Toledo STP Data: 18-25 September 1974	49
6-1	Daily Discharge and Fluxes at Waterville: USGS Data, 1965-1970	55
7-1	Perrysburg Bridge, 10 May 1974	90
7-2	Perrysburg Bridge, 11 May 1974	91
7-3	Cherry Street Bridge, 11 May 1974	92
7-4	Cherry Street Bridge, 12 May 1974	93
7-5	Mouth, 11 May 1974	94
7-6	Mouth, 12 May 1974	95
7-7	Key to Sampling Stations in the Maumee River Survey, September 1974	101
7-8	Maumee River Survey, September 1974: Laboratory Results	102
8-1	Identification of Maumee River Basin Sediment Samples: 19 May 1974	121
8-2	Analysis of Maumee Basin Sediments: 19 May 1974	122
A2-1	USGS Flow Measurements, 20-23 September 1974	162
A2-2	Swan Creek at Scott Road, Route 20A, Byrne Road, and Monroe Street, 27 September - 10 October 1974	164
A2-3	Tenmile Creek/Ottawa River at Silica Drive, Monroe Street, Stickney Avenue, and Summit Street, 27 September - 15 October 1974	165
A2-4	Mouth of Coast Guard Slip, 25 September 1974	169

Copies of this document are available
to the public through the
National Technical Information Service
Springfield, Virginia 22151

1. CONCLUSIONS

The Maumee River estuary, for much of its fifteen mile length, and its tributaries in Toledo are polluted. Sludge banks, oil slicks, and sewage stenches foul the area. The city's sewer system (especially the regulators) is in sad disrepair: Too often sewage flows out when the river is low, and when the river is high it flows into the sewers and floods the sewage treatment plant (STP). Although the city has modernized and expanded its STP, both the new facilities and their operation leave something to be desired: Even though the plant often achieves an excellent effluent, there are many days when the effluent is deplorable (e.g. during our September 1974 survey there were days when it was paradoxically much worse than raw sewage). In any case, a great deal of waste never gets to the plant, particularly in wet weather, because it is lost in transit through the overloaded, leaky sewers. Moreover, the city exercises little control over what goes into (and leaks out of) the sewers: The sewer permit program is a dusty fossil.

Despite the gross pollution, few of the numerical water-quality standards (WQS) are violated. The two principal violations are dissolved oxygen (which is too low) and fecal coliform bacteria (which are too numerous). Toledo Edison's Acme powerplant raises the water temperature more than 3° C far beyond the permitted mixing zone; yet the fish, including some mammoth pickerel, don't seem to mind in the least: The warm outfall is one of their favored habitats. Despite the organic and nutrient enrichment, the main stem of the Maumee does not even approach a violation of the ammonia standard; however, the waters of the Coast Guard slip (near the mouth of the river) and places in Swan Creek (in the dry September of 1974) did violate the ammonia standard, interpreted as total ammoniacal nitrogen (see p. 25).

The non-numerical standards embodied in the "four freedoms" fare far less well. The sludge banks throughout Toledo (especially below river mile 6) make the water bubble like a glass of root beer and crackle like a bowl of Rice Krispies; anyone who cares to walk along Promenade Park may see the sludge bubbles, tally their tiny telltale oil slicks, and (especially in summer) inhale the unmistakable fragrance of decomposing excreta. The mouth of Swan Creek is frequently septic and smells it. Floating filth and debris, whose provenance is unmistakably cloacal, are common near the outfalls of the downtown sewers. Bad as conditions are, they would surely be worse if the Corps of Engineers did not frequently dredge the Maumee's deep navigation channel; in addition to removing the heavy sediment load which settles in the generally calm waters of the estuary, the dredgers perform the valuable service of mucking out the slops from the diarrheal sewers.

The lower Maumee River is an estuary. Lake effects (flow reversal, sudden -- often dramatic -- changes in stage and volume, vertical and horizontal stratification, stagnation, and extreme flow instability) are felt up to the riffles (which extend from approximately river mile 15 to RM 30) just above the Perrysburg Bridge. The hydraulics of this estuary (and their consequences for wastewater planning and pollution control in Toledo) have never been given more than stingy lip service in any State or Federal report on pollution in these waters; they are often completely overlooked.

We cannot overemphasize that the droughtflow of the Maumee River has nothing whatever to do with the quantity or exchange rate of water in the estuary. The Maumee estuary is controlled by the level of western Lake Erie and by the winds. When the winds blow steadily out of the southwest, the lake falls at Toledo and the water stored in the estuary spills out; when the winds blow out of the northeast, the lake rises at Toledo and the resulting estuarine backflow may drown the lower end of the riffle above the Perrysburg Bridge. In effect, the estuary is a huge, flat lagoon which receives the waters of the free-flowing Maumee, the outflows from the sewers and treatment plants of the Toledo area, and the great volumes of Lake Erie water that enter it when backflow is induced by rising lake levels. Obviously this great "slosh basin" cannot be treated as a free-flowing stream in the making of wasteload allocations. In fact, the flow which enters the upper end of the estuary (as measured at RM 21 by USGS' Waterville gage) is seldom an important hydraulic factor. Until the estuarine hydraulics are well understood, work on mathematical models and the usual wasteload-allocation techniques must be stopped.

Failure to give hydraulics their due is matched by persistent weaknesses in water-quality data. None of the routine monitoring programs around Toledo (there are several) produces valid data on water quality. None of the fixed-point sampling stations (be they continuous, daily, weekly, or monthly) can provide adequate data on waters which are subject to vertical and horizontal stratification. Too many samples are taken near the shore and near the water surface, where boundary-layer effects distort the sample. Except when the estuary is thoroughly mixed, no single point can give a fair picture of water quality throughout an estuarine cross-section. The sampling apparatus is commonly inadequate: All samples must be taken with a flow-through device, aligned with the current, and equipped with a messenger for sampling at all depths up to 30 feet. Sample storage and preservation are often suspect; moreover, storage times are much too long in some of the laboratories. Few of the analytical laboratories pay sufficient attention to quality control, and none of them routinely checks the accuracy of its procedures against analytical reference samples which are readily available from the U. S. EPA. Because techniques of sampling and analysis are not standardized, there is no comparability among the data of the several monitoring programs; furthermore, some of the laboratories use analytical methods and shortcuts (such as Hach reagent pillows) which are not approved by the U. S. EPA. Nearly all these deficiencies can be remedied for trivial sums; greater coordination and cooperation might even bring about significant savings.

Far too much money is spent on technically deficient sampling and water-quality analysis. The bubbling sludge beds, leaky sewers, and gagging miasmas can be far more easily and cheaply detected by the unaided eye and nose than by the suspect methods of scientism run amuck. The two principal violations of WQS, low DO and high fecal coliform densities, occur just where anyone with normal vision and olfaction would think: near the sludge beds and dribbling sewers in downtown Toledo, and near the STP. The river is abnormally warm near the huge cooling-water discharge from Toledo Edison's Acme plant. There are no important subtleties. The pollution problems have long been evident. The cures are the obvious ones: Upgrade the sewers to eliminate the sludge beds and improve STP performance. Unless the Acme plant is given a variance for its cooling-water discharge, it will violate the current temperature standards. Until these persistent problems have been cured, there is no reason to spend another dollar on routine water-quality monitoring.

The sediments in the lower Maumee and its tributaries are not innocent clays and sands. They are oxygen-demanding, rich in nutrients, and loaded with oils and grease. Throughout the long intervals when the estuary is either stagnant or in reverse flow, the Maumee sloshes back and forth over this bed of soft goo. The DO drops, suspended solids settle, and the Maumee's longitudinal profile shows a simultaneous DO sag and BOD sag. Although improved waste collection and treatment will alleviate this problem, they may not entirely cure it, because most of the solids and more of the dissolved matter is already seen at the Perrysburg Bridge -- well above Toledo, at the head of the estuary, but below about 6,300 square miles of flat, soft lands which are largely given over to the rich agriculture that has transformed this region from dense forest and impassable swamp into heavily fertilized, heavily sprayed fields. Much more attention should be given to these upriver areas, with special emphasis on soil conservation and on more efficient use of agricultural chemicals. If Toledo were to be wiped off the map (which is one final solution to the zero-discharge problem), the lower Maumee would still be muddy, rich in nutrients, and loaded with BOD. Bacterial densities would almost certainly fall, thermal discharges would cease, and the DO would probably be much higher -- although one wonders how long the DO would remain high if the Corps of Engineers were to cease dredging the harbor channel.

Area sources and the upstream heritage of pollution merit the most careful consideration. Landwash is one of the most important area sources in the Maumee basin. During rainy spells, when the river is discharging more than usual, soil particles (sediment) and agricultural chemicals are washed from the land into the river, which transports them to the estuary and Lake Erie. Sediment analyses by the USGS provide striking evidence of landwash effects. Figure 1-1 shows daily discharge (in cfs) and the daily sediment load (in tons per day) at Waterville between October 1966 and March 1967 -- an interval of extremely low and extremely high flow. The daily discharge during these six months varied from about 100 cfs to 80,000 cfs. At very low flows, sediment loads were often less than five tons a day; but at flood peaks, there was about one ton of sediment for each cfs of discharge. In the most extreme case, when the discharge was 68,800 cfs, the sediment load was over 150,000 tons a day. Nothing in Toledo contributes loads remotely approaching this magnitude.

The Maumee River at Perrysburg Bridge also provided striking evidence of landwash during our two surveys. In our May survey -- following a wet winter and spring -- the river's discharge was 5500-6000 cfs; in our September survey, the Waterville discharge had remained at about 400 cfs for several months. Table 1-1 shows dramatic differences in the flowing loads of every kind of pollution.

Figure 1-1.

Flow and Sediment Loads at Waterville (USGS #04193500): October 1966 - March 1967

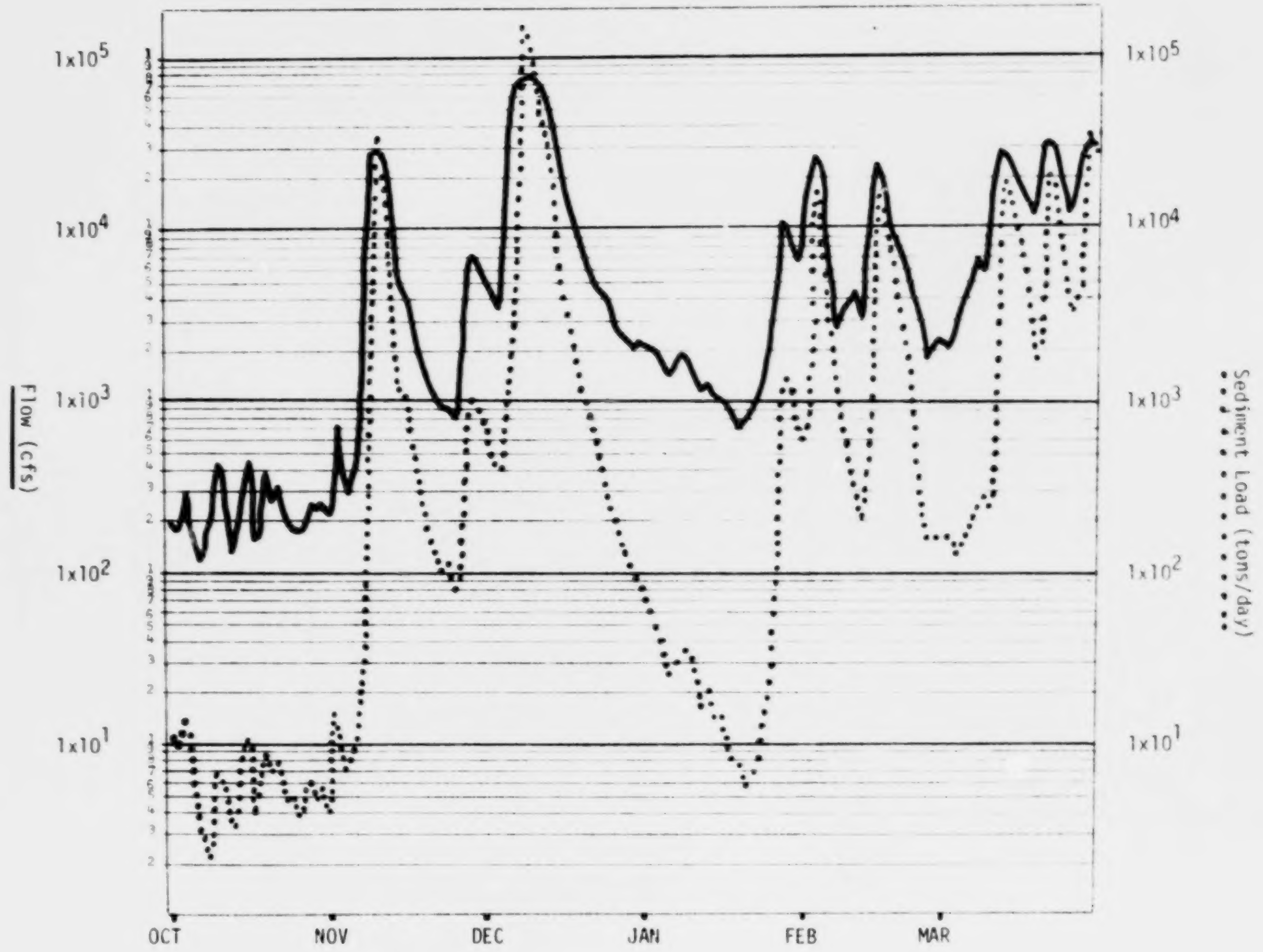


Table 1-1. The Upstream Heritage and Area-Source Effects: The Maumee River at Perrysburg Bridge on 10-11 May 1974 and on 20 September 1974.

Date	10 May '74		11 May '74		20 Sept. '74	
Waterville Discharge	5520 cfs		6050 cfs		433 cfs	
	mg/l	Flux*	mg/l	Flux*	mg/l	Flux*
Suspended Solids	43	1,300,000	59	1,900,000	38	89,000
Total Dissolved Solids	474	14,000,000	445	15,000,000	532	1,200,000
Total Organic Carbon	13.2	390,000	16	520,000	24	56,000
Total Nitrogen	3.1	92,000	2.96	96,000	0.96	2,200
Total Phosphorus	0.19	5,700	0.2	6,500	0.3	700
COD	35.1	1,000,000	47	1,500,000	41	96,000
20°-BOD_5	5.7	170,000	7.2	230,000	6	14,000
20°-BOD_{30}	21.4	640,000	18.2	590,000	13	30,000

---

* Flux is flowing load in pounds per day.

These differences have nothing to do with Toledo, but much to do with landwash; they also underscore the size of the upstream heritage, especially in wet weather.

One must bear in mind that the lands around the lower Maumee were malarial swamps until the last half of the nineteenth century. Although Toledo is not paradise now, it was, according to reliable accounts of the early settlers, hell then. It is all too easy to see now that by draining the swamps, denuding the soils for farming, and permitting discharges into the slowly sloshing estuary of the Maumee, water quality in Toledo was sure to suffer. By radically altering land uses and by moving all discharges from the estuary to Lake Erie (just as Toledo has moved its water-supply intake from the river to the lake), the estuary would undoubtedly become much cleaner. Although the costs would be staggering, other cities have rerouted their discharges (e.g., Seattle, Chicago, Portland, Modesto), and Toledo might look into this possibility. Whether the costs would be justified by the results is another matter entirely.

With decent improvements in Toledo's sewers and STP effluent, the lower Maumee should be able to meet all the standards that have been established; the sole exception is the thermal effluent from Toledo Edison's Acme plant, whose effects extend beyond the current definition of a mixing zone. Because solids from upstream drainage areas settle in the Maumee estuary, it is possible that even with these improvements in Toledo there will be occasional DO violations, especially when winds and lake levels combine to pen up and stagnate the lower river, and to rock the Maumee gently back and forth over an organically enriched bed of soft, finely divided clay.

Because our surveys were conducted in 1974, when the level of Lake Erie and the estuary was very high, it is certain that we never saw anything like "worst conditions" in the lower river. The low water datum (LWD) for Lake Erie is 568.6 ft above sea level; the lowest monthly stage seen since 1860 is 567.5 ft. During our May survey the stage was 571.43 - 573.93 ft; in September it was 570.61 - 572.83 ft (see figures 7-3 to 7-15). Since the estuary's area is about 120 million square ft, each foot of stage adds 120 million cubic ft of water to the lower river. The maximum volume in May was 650 million cubic ft above LWD; even the minimum volume in September (245 million cubic ft above LWD) is not trivial: 245 million cubic ft is equal to three weeks of discharge from the Toledo STP. It would have taken a week of Waterville flow at 400 cfs to have accumulated 245 million cubic ft, which is not the volume of the estuary but only the lowest excess over LWD we saw: It would have taken several weeks of flow at 400 cfs to fill the entire estuary. Poorest water quality in Toledo is likely when very low lake levels combine with light northeast winds to fill the estuary with river water and to stagnate it at a stable stage of 568 ft. Nothing resembling this hydraulic condition occurred in 1973 or 1974. It bears repeating that Waterville droughtflow has nothing to do with worst conditions in the estuary. Low flow may help: Insofar as lake water is much cleaner than river water, the estuary is cleanest when drought coincides with very high lake stage, especially in winter.

Although we did not see the estuary at its hydrological worst, the STP effluent during the September survey was shocking, owing to spills of accumulated solids. During the interval 18-25 September, effluent loads (in pounds per day) were as follows:

20° -BOD$_5$	18,000 - 107,000; 62,000 (median)
SS	18,000 - 424,000; 143,000 (median)
Total P	1,174 - 15,588; 3.500 (median)
NH_4 (N)	5,598 - 9,250; 7,356 (median)

In May the plant was much better behaved, but the sewers were badly leaking, owing to the high water table and the rains, which were sometimes torrential. All these differences notwithstanding, concentrations of pollutants in the lower river were surprisingly similar in both surveys. Samples from the river's mouth (both taken near the end of an exaggerated estuarine flush, when the river was rapidly spilling into a lake which had precipitously fallen under the influence of steady southwest winds) show that, in some respects, the river was cleaner in September than in May (see table 1-2). Despite the smaller estuarine volume. Despite the poor STP performance. Despite the dramatic differences in the riverflow at Waterville (6,000 cfs in May versus 400 cfs in September). Leaky sewers and the upstream heritage are at least as important as STP performance in accounting for these nearly invariant concentrations.

There was, however, one very significant difference in water quality. Dissolved oxygen was always above 5 mg/l in the May survey, but was frequently below 4 mg/l in September. Long stagnation times in the estuary and much warmer water (20° C in September versus 14° C in May) are to be blamed at least as much as the shoddy STP performance. The DO standard of 5 mg/l was never violated upriver of the DiSalle Bridge (RM 6.9), but was frequently violated from the Anthony Wayne Bridge (RM 5.4) to the mouth. The violations were most severe near the Craig Bridge (RM 3.6), which is just below the Acme powerplant's cooling-water discharge (approximately 316 mgd -- nearly 490 cfs) and within three miles of nearly all the sewer outfalls and the STP itself. The vacillating, unstable currents in the estuary obscure the full effect of the warm outfall on the river's temperature and DO; but the long detention of the water in the estuary no doubt exacerbates the deoxygenating effect of Acme's discharge.

In summary, if something is done to improve Toledo's sewerage, our best judgment is that the Maumee estuary should be classed as an

Table 1-2. Pollutant Concentrations at Mid-Mouth (Mid-Depth) in the Maumee River, 12 May 1974 and 25 September 1974.

	12 May 1974	25 Sept. 1974
SS	42 mg/l	46 mg/l
TDS	417	318
Total C	46.4	38
Inorg. C	33.3	17
Org. C	13.1	21
Total N	2.25	2.15
Kjeldahl N	0.52	1.08
NH_4 (N)	0.27	0.50
NO_3 (N)	1.42	0.40
NO_2 (N)	0.040	0.170
Total P	0.20	0.22
Dissol. P	0.13	0.16
COD	40.5	27
20°-BOD_5	5.9	4
20°-BOD_{10}	8.9	4
20°-BOD_{20}	15.0	6
20°-BOD_{30}	15.3	7

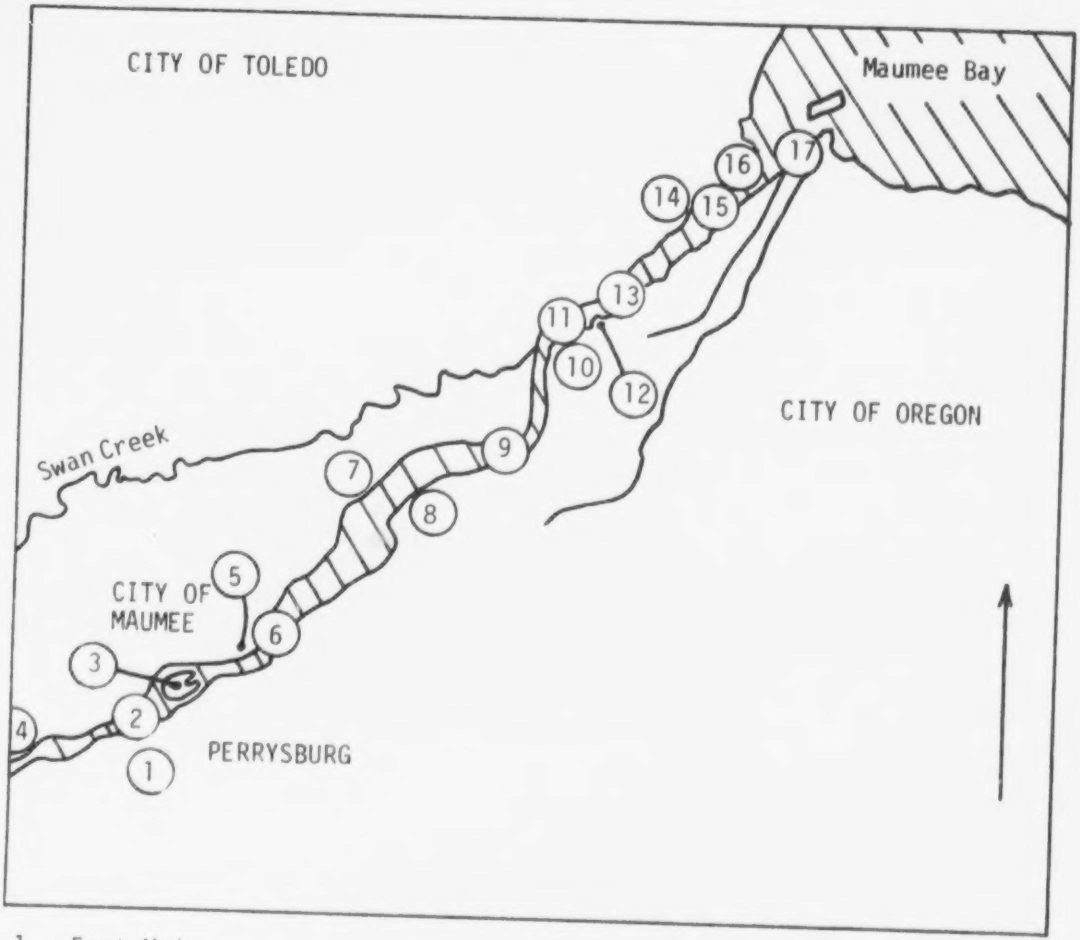
effluent-limited segment. Best practicable technology, as it is now defined, should be sufficient to ensure that the estuary will meet all water-quality standards.[1] If the sewers continue to leak, thereby feeding the sludge beds in the river, the estuary's DO will probably continue to violate standards, and bacterial concentrations will certainly remain too high. The STP will require structural modification to meet the definition of BAT for the early 1980's. The STP effluent today is often inadequate, owing to both operational and design problems; the Toledo Metropolitan Area Council of Governments will soon issue a separate report on them. Elegantly designed facilities will do nothing to improve the estuary if they are not well maintained and well run. Improved nutrient removal by the STP may lower concentrations of nitrogen and phosphorus in the estuary, but nutrient loads will be high no matter what Toledo does: When the Waterville flow is over a few hundred cfs and the STP is operating well, most of the nutrients in the estuary originate in the agricultural drainage area well above Toledo.

Figures 1-2 and 1-3 are site location maps for the lower Maumee and Toledo.

---

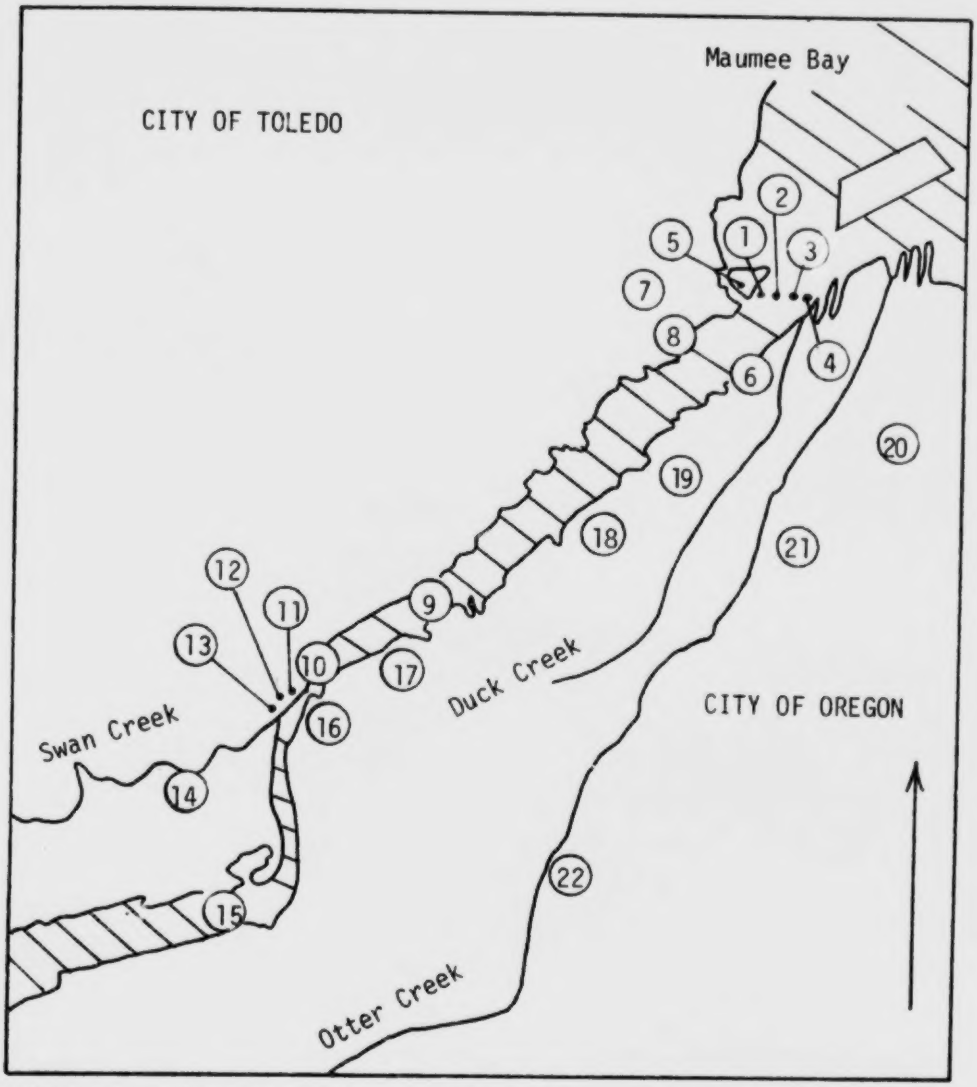
[1] Discharge permits have been summarized in a recent report: OEPA (May 1974). State of Ohio, Maumee River Basin Waste Load Allocation Report for the 303(e) Continuing Planning Process for Water Quality Management. Draft. Part 2. Undated, unpaginated.

Figure 1-2. Lower Maumee River Site Map


CITY OF TOLEDO
Maumee Bay
CITY OF OREGON
Swan Creek
CITY OF MAUMEE
PERRYSBURG
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

1. Fort Meigs
2. Perrysburg Bridge
3. Ewing Island
4. Lucas County STP at Maumee
5. Fort Miami
6. I-80/90 Bridge
7. Walbridge Park
8. Rossford Marina Pier
9. DiSalle (I-75) Bridge
10. Toledo Pollution Control Agency (TPCA)
11. Cherry Street Bridge
12. Sports Arena
13. I-280 Bridge (Craig Bridge)
14. Harrison Marina Pier
15. Toledo Terminal Bridge
16. Toledo STP
17. C&O Coal Dock

Figure 1-3. Toledo Site Location Map


Maumee Bay
CITY OF TOLEDO
CITY OF OREGON
Swan Creek
Duck Creek
Otter Creek
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

1. White Buoy (Mouth West)
2. Buoy 50 (Mouth Midwest)
3. Buoy 49 (Mouth Mideast)
4. Coal Docks (Mouth East)
5. Coast Guard Station
6. Port of Toledo, Presque Isle Facilities
7. Bay View Park
8. Toledo STP
9. I-280 Bridge (Craig Bridge)
10. Cherry Street Bridge
11. Promenade Park
12. Jefferson Street Regulator
13. Monroe Street Regulator
14. Hamilton-Newton Regulator
15. DiSalle (I-75) Bridge
16. Toledo Pollution Control Agency (TPCA)
17. Toledo Edison Co. (Acme Station)
18. Interlake, Inc.
19. Gulf Oil Co.
20. Standard Oil Co.
21. Toledo Water Works
22. Sun Oil Co.

2. BACKGROUND AND DESCRIPTION OF THE AREA

The Maumee River drains over 6,500 square miles in northwestern Ohio, northeastern Indiana, and southern Michigan. Its main stem begins at Ft. Wayne, where the St. Joseph and St. Marys Rivers unite, and flows generally northeast to Toledo, about 135 miles distant. It empties into Maumee Bay, a shallow bowl at the tip of Lake Erie. This entire area was once covered by ancient Lake Erie, which formerly drained into the Mississippi basin: The outlet was near Ft. Wayne; the Wabash River carried the lake's discharge to the southwest. Although later glaciation changed these drainage patterns time and again, the present topography bears witness everywhere to the drowned and glaciated past. The land is flat and poorly relieved; the river has little gradient (1.3 ft/mile), hence its sluggish flow. There are a few outcroppings of hard Niagaran dolomite (e.g., in the 15-mile riffle from Grand Rapids to the Perrysburg Bridge), but the basin's predominant feature is its extremely fine clay soil, derived from the rock flour which was created by the grinding action of the glaciers, by weathering under climatic extremes, by lush swamps, and by severe erosion and sedimentation over geologic time; many of these fine clay particles are of nearly colloidal size. The poor relief, gentle gradient, and powdery soils account for many of the Maumee's traits: its muddiness, low velocity, and sediment-clogged bed. Although the Maumee is not a large river (its mean discharge to Lake Erie is only about 5,000 cfs), it is the largest tributary to the Great Lakes.

The estuary of the river begins just above the Perrysburg Bridge, where the riffles end (RM 14.5, approximately). The shallow water courses swiftly over the crystalline rocks of the riffles, which are usually scoured clean of sediment deposits. As soon as the water enters the estuary, its velocity abruptly drops unless the estuary is flushing hard -- a few times a month, in general. The river bottom reflects this abrupt change in velocity: It changes from hard rock to soft, plastic clay. As the currents diminish, suspended solids begin to settle, and the DO begins to fall. This initial drop in DO has almost nothing to do with BOD from the Toledo area: It is rather a purely physical phenomenon deriving from the altered flow regime.

Within the estuary currents are extremely unstable, there is frequent reverse flow due to fluctuations in Lake Erie's stage, and the water is relatively stagnant for long intervals. The estuary is broad and deep: nearly a mile across at its widest (near Grassy Island, approximately RM 8), and nearly 30 feet deep in the dredged navigation channel. Early maps and charts show that the estuary was frequently 25 feet deep even before the Corps of Engineers began to improve the harbor. The soft estuarine bed is unstable: Bars of clay, sand, and gravel are in continual motion. When the estuary is flushing hard, or when floodcrests rush down the river, the soft bottom is roiled up by turbulent flow and scoured into Maumee Bay. It is profitable to consider the estuary a reservoir, a sloshing dilution basin (where river water is progressively mixed with backflow from the lake), and a large settling basin (where solids from upriver are sedimented, added to by Toledo, and occasionally scoured).

The Maumee basin today is an intensively developed area. The flat terrain has been exploited by farmers (the major crops are corn, soybeans, soft winter wheat, tomatoes, and truck-garden specialty crops). The principal centers of population and industry are Ft. Wayne, Lima, and, above all, Toledo, which is one of the largest and busiest ports in the Nation. The industrial and commercial base is diverse: agriculture and food processing, oil refining and petrochemicals, metals, auto parts, heavy machinery, glass manufacture, tool-making, and transportation.

Toledo, at the western end of Lake Erie, has become the busiest port on the lake and one logical turn-around point for St. Lawrence Seaway traffic: It annually handles more than 25 million tons of soft coal and iron ore, and another 2-3 million tons of grain and other bulk cargoes. Toledo is also one of the Nation's largest rail centers: Most of the iron and coal is transferred at the port facilities between lakers and freight cars, for overland shipment to the steel plants which are clustered around the southern rim of the Great Lakes and the edge of the Appalachian coalfields. Metropolitan Toledo has a population of about 500,000; some of the major industrial firms there are Owens-Illinois, Owens-Corning Fiberglas, Libbey-Owens-Ford Glass, SOHIO, Sun Oil, Gulf Oil, Pure Oil, Dana Corp., American Motors-Jeep, Champion Spark Plug, DeVilbiss Co., and the Toledo Scale Corp.

Although Lake Erie was the first of the Great Lakes to be formed, it was the last to be discovered by Europeans, and the Maumee basin was one of the last areas around Lake Erie to be settled. The settlement of this basin and its conversion, within the space of a century, from impenetrable swamp and dense forest to rich farmlands and industrialized cities are among the most startling transformations ever wrought on this continent. The early history and gradual development of this region have been recorded in several excellent accounts[1].

---

[1] BROWN, Samuel R. (1815). Views of the Campaigns of the Northwestern Army, etc. Wm. G. Murphy, Philadelphia.

DOWNES, Randolph C. (1949). Canal Days: Lucas County Historical Series, vol. 2. The Historical Society of Northwestern Ohio, Toledo.

DOWNES, Randolph C. (1951). Lake Port: Lucas County Historical Series, vol. 3. The Historical Society of Northwestern Ohio, Toledo.

(continued)

Good topographical maps and navigation charts of Maumee Bay and the lower Maumee River were published by the U. S. Bureau of Topographical Engineers (now in the Corps of Engineers) as early as 1844. New surveys, charts, and maps have been published with increasing frequency since then. These historical materials describe the cutting down of the forests, the backbreaking labor of installing tile drainage in the first marshy farmlands, the rapid destruction of fish and waterfowl, the navigation improvements, the landfills, and the accelerating population and industrialization. Although inadequate sewers and waste treatment account for at least some of the Maumee's problems today, the major changes in the water are apparently even more closely related to the radical changes in land use. These changes include the drop in water table, increased turbidity and sediment load, and more rapid, more extreme variations in stage. The

---

(continued)

DOWNES, Randolph C. (1954). Industrial Beginnings: Lucas County Historical Series, vol. 4. The Historical Society of Northwestern Ohio, Toledo.

EVANS, Estwick (1832). Pedestrious tour of 4,000 miles during the winter and spring of 1818. In: U.S. CONGRESS, American State Papers, Class X, Miscellaneous. vol. 2. Gales & Seaton, Washington.

HATCHER, Harlan (1945). Lake Erie. Bobbs-Merrill, Indianapolis and New York.

KAATZ, Martin R. (Winter 1952-1953). The settlement of the Black Swamp of Northwestern Ohio: Early days. Northwest Ohio Quarterly 25(1):23-36.

KAATZ, Martin R. (Summer 1953). The settlement of the Black Swamp of Northwestern Ohio: Pioneer days. Northwest Ohio Quarterly 25(3):134-156.

KAATZ, Martin R. (Autumn 1953). The settlement of the Black Swamp of Northwestern Ohio: Later days. Northwest Ohio Quarterly 25(4):201-217.

MAYFIELD, Harold (Spring 1962). The changing Toledo region -- a naturalist's point of view. Northwest Ohio Quarterly 34(2):83-104.

OHIO GEOLOGICAL SURVEY (1838). Second Annual Report. S.Medary, Columbus.

SLOCUM, Charles E. (1905). History of the Maumee River Basin from the Earliest Accounts to Its Organization into Counties. Privately printed by the author, Defiance, Ohio.

VAN TASSEL, Charles S., editor (1929). Story of the Maumee Valley: Toledo and the Sandusky Region, vol. 1. S. J. Clarke, Chicago.

once-teeming fishlife is greatly reduced, the waterfowl almost vanished, and the vegetation altered almost beyond recognition.

Samuel Brown, who was not a land speculator but an officer attached to General (later President) Harrison, described the Maumee and the Black Swamp before this radical transformation began. The Black Swamp occupied about a quarter of the basin, generally to the south and east of the river itself, and included large stretches of the river valley.

> "The quantity of fish at the rapids [scil. Grand Rapids] is almost incredible.... So numerous are they at this place, that a spear may be thrown into the water at random, and will rarely miss killing one! I saw several hundred taken in this manner in a few hours. The soldiers of the fort [Fort Meigs, just above Perrysburg Bridge] used to kill them in great quantities, with clubs and stones. Some days there were not less than 1,000 taken with the hook within a short distance of the fort, and of an excellent quality.... The river, Swan Creek [in the heart of downtown Toledo today], and the shoals of the bay, swarm with ducks, geese, etc. He [scil. the hunter] need not wait one minute for a shot.... The woods are filled with deer, elk, and wild turkies." "[In the Black Swamp we] found the grass higher than our heads and as thick as a mat, confined together by a species of pea vine, which compelled us to tread it under our feet to make the least progress; this operation was too slow and fatiguing to be long continued...and in the course of a few rods we had disturbed several rattle snakes...." "The grass was about seven feet high and so thick that it would easily sustain one's hat -- in some places a cat could have walked on its surface; in many places it was effectually matted by vines that required one's whole strength to break it down. To break the road four rods was as much as the best of us could perform at one turn." Op. cit., pp. 138-144 passim.

Kaatz' thorough review contains a telling description of the heroic labors that went into claiming this land for civilization:

> "The magnitude of the pioneer's labor rightly fills us with awe. For the pioneer who selected land within the borders of the Black Swamp, the effort required to live and get along was even greater. His land was either wholly or partially covered by water except for a short part of the year. The soil was heavy, sticky clay. The insects were so bad that the settler often had to wrap himself in heavy clothing despite the heat. Oxen had to be used instead of horses, for the mud, brush, and insects were too much for the latter. Finally the crop was planted only to have the excessive moisture cause the wheat and oats to overgrow, fall down and blast, and sometimes not before harvest time." Kaatz (Summer 1953). Op. cit., p. 151.

Slocum was both a physician and a polymath. Since water pollution was once almost exclusively assigned to State Health Departments, Slocum's description of common diseases in the Maumee basin during the last half of the nineteenth century may put the development of this region into a perspective quite different from a naturalist's:

> "Swamp miasms were rife from the first records of this Maumee region and during the period of clearing away the forest, the opening of the ground to the direct rays of the sun, during the earlier turnings of the soil in its cultivation, and in public works. Ague -- intermittent fever -- in its different forms, and the severer remittent fevers, were quite general and severe until the year 1875 in most parts of the Basin; and in the less developed parts these diseases continued for several years later. The writer, in the practice of his profession, has treated virulent types of these affections in many families where there was not a member in good health to nurse those dangerously sick. These diseases were

most prevalent in severe and dry summers; and the following winters inflammatory diseases were numerous and virulent on account of the weakened condition of the people from the malaria. The death rate, although no higher than in other places throughout the country, was greater those years than it has been since. In fact, since the passing of the swamps and their miasms the healthfulness of this Basin ranks very favorably with that of any region in America." *Op. cit.*, p. 3.

3. WATER QUALITY STANDARDS (WQS) IN THE TOLEDO AREA

Ohio's WQS for the Toledo area have been in flux since they were established. The first set of standards was adopted on 10 January 1967, and covered the Maumee River, Maumee Bay, and their tributaries. All these waters were to be free from (1) discharges that "will settle to form putrescent or otherwise objectionable sludge banks"; (2) "floating debris, oil, scum, and other floating materials... [from] discharges in amounts sufficient to be unsightly or deleterious"; (3) "discharges producing color, odor, or other conditions in such degree as to create a nuisance"; and (4) "discharges in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life." In addition to these "four freedoms", all waters must be suitable for all designated uses, except for the main stem of the Maumee in Toledo, which was only required to meet standards for industrial water supply and for "aquatic life B" (warm-water fishery).

The most recent standards, adopted 27 July 1973, classify all waters of the State for "warm water fisheries, for primary contact recreation, for processing by conventional treatment into public, industrial, and agricultural water supplies". The standards do not apply when the streamflow falls below "the annual minimum 7 day average flow that has a recurrence period of once in ten years", nor do they apply to low-flow streams, which are defined as having an "upstream drainage area... less than five square miles" and "less than 50% of the flow would be present if there were no point source wastewater discharges for 15% of any two consecutive year period during the ten years preceding July 1, 1974". The new standards preserve the "four freedoms", but substitute a specific bioassay procedure for the sweeping (and rather vague) toxicity freedom of the old standards.

There are several significant differences between the old and the new standards. Under the 1967 standards, coliform bacteria above the

Toledo area must not exceed 1,000 per 100 ml as a monthly average value (either MPN or MF count); the 80th percentile must not exceed 1,000 per 100 ml, nor may the 95th percentile exceed 2,400 per 100 ml. DO must be over 3 mg/l at all times, and at least 5 mg/l "during at least 16 hours of any 24-hour period". The pH must never fall outside the range 6.5-9.0 (amended within the year to 6.5-8.5). Dissolved solids must never exceed 1,000 mg/l, nor may the monthly average ever exceed 750. Within the Toledo area, the bacterial standard was waived (because the water was not protected for either public water supply or recreational uses); the DO standard was dropped to 2, with no value ever to be less than 1 (this standard too was amended within the year: By October the average DO had to be at least 3, and the daily minimum at least 2). Water temperature must never exceed 95°F (35°C).

The new standards are quite different -- in some cases they are much more demanding, in others they are much more permissive. The DO standard is higher: a daily average of 5, and never less than 4. The pH standard is laxer: 6.0-9.0. The coliform standard is different: "fecal coliform content (either MPN or MF count) shall not exceed 200 per 100 ml as a 30 day geometric mean based on not less than five samples during any 30 day period nor exceed 400 per 100 ml in more than ten percent of all samples during a 30 day period." The dissolved-solids standard is lower: Samples may now exceed "one, but not both, of the following: (1) 1500 mg/l, (2) 150 mg/l attributable to human activities." The temperature standard is much stricter: "stream water temperature shall not exceed by more than five degrees farenheit (2.8 degrees centrigrade) the water temperature which would occur if there were no temperature change of such waters attributable to human activities." It is further prescribed that no water in the Maumee basin may ever exceed 90°F (32.2° C). Although no standard is set for phosphate, total nitrogen, nitrates, nitrites, or Kjeldahl nitrogen, the maximum allowable concentration of ammonia is 1.5 mg/l. No mixing zone may exceed 12 acres.

The estuary and its tributaries have never consistently met even the lowest DO and bacterial standards; they have always met the pH and dissolved-solids standards. The new mixing-zone standard is violated by Toledo Edison's Acme powerplant. The Maumee River did not violate the ammonia standard in either our May or September 1974 surveys, but several nearby waters did (see Appendix 2). The worst ammonia violation was in the upper reaches of Swan Creek: far above Toledo, but below more than five square miles of drainage area; moreover, the flow was above the 7-Q-10 droughtflow: This was not a "low-flow segment". The "four freedoms", however, are widely, frequently, and severely violated.

The language of these standards merits very careful attention, since Ohio's WQS are similar in their imprecise, prolix form of expression to the WQS in many other States. The DO standard specifies an absolute minimum as well as a daily average. Nowhere is one told where these measurements are to be taken. Although the muddy Maumee estuary is so turbid that there is no clear sign of diurnal DO variation due to photosynthesis, there is plenty of DO variation. DO is always high at the Perrysburg Bridge, at the foot of the long riffle; DO is always low over the sludge beds below RM 6, particularly near the Acme plant's warm outfall. Everyone knows that a DO probe will read zero near the bottom of a sludgy river, where the bottom is in any case ill-defined. The eutrophic waters in the riffle no doubt do exhibit diurnal DO variation -- there are plenty of filamentous algae about -- but physical reaeration is so violent the DO will rarely fall below 5. It is no trick to find places in the Maumee that will always have DO less than 4, nor is it hard to find places that will always have DO above 10. Depending on how one selects sampling points, one may make the Maumee look as clean or as dirty as one pleases -- at the minimum or on the average.

The new ammonia standard should be changed: It says "ammonia", but means "NH_3 & NH_4". Within the usual ranges of pH and temperature, nearly all ammoniacal nitrogen is ionized NH_4, but NH_4 is not the principal toxic culprit: Un-ionized NH_3 is. Although the standard refers to STORET Number 00610 -- which is not one, but several methods for "Nitrogen, Ammonia" -- all these methods detect NH_3 and NH_4, not just NH_3. For technical reasons which have nothing to do with ionization states in natural watercourses, all the 00610 methods convert NH_4 to NH_3 by pH adjustment, distillation, or both. The confusion also appears in OEPA's wasteload-allocation report for the Maumee basin,[1] which uses "NH_3", not "NH_3 & NH_4" or "ammoniacal N". OEPA's standard limits "ammonia" to "1.5 mg/l", which (taken literally) is very permissive: The European Inland Fisheries Advisory Commission[2] recommends that ammonia (but not total ammoniacal nitrogen) be limited to 0.025 mg/l, and there is strong support in the U.S. for this limit. We suggest that the standard be changed to conform with EIFAC's recommendation, and that the laboratory methods for ammonia detection be revised to stop the confusion of ammonium with ammonia.

In actual fact, most of the State's data on the Maumee are derived from monthly grab samples, but most of the samples are collected and analyzed by the Toledo Pollution Control Agency (TPCA), not by the Ohio Environmental Protection Agency. The Federal program of data collection resides largely with the USGS, which maintains automatic monitors for DO, pH, and conductivity at Waterville and at Toledo's Coast Guard Station, near the river's mouth. USGS does take monthly or biweekly grab samples at Waterville; but water-quality conditions at Waterville -- even if one believes the USGS data -- haven't the remotest connection with conditions in the estuary. If the OEPA has no intention of vicariously measuring the river more than a few times a month, the language of the WQS bears little relation to the surveillance activities that are supposedly undertaken to support them. The discrepancy between language and reality is misleading. For example, if only one or two monthly samples are analyzed for bacteria at each sampling point, it is senseless to talk of monthly averages and 90th percentiles "based on not less than five samples during any 30 day period". Moreover, it is impossible to compute an average from an open-ended distribution (e.g. bacterial assays, which commonly give results such as "too numerous to count", or "less than 10 cells per ml", or "greater than 700,000").

---

[1] OEPA (May 1974). State of Ohio, Maumee River Basin Waste Load Allocation Report for the 303(e) Continuing Planning Process for Water Quality Management. Draft, section 5. Undated and unpaginated.

[2] EIFAC (1970). Water quality criteria for European freshwater fish: Report on ammonia and inland fisheries. Food and Agriculture Organization of the United Nations. Rome, Italy.

The pH standard shows how inconsistent the standards are among themselves: Although other standards are burdened with supererogatory statistical talk of averages and percentiles, the pH standard merely specifies a maximum and a minimum. Yet surveillance for pH violations is identical to surveillance for any of the other standards: The same grab samples are used. Even if the "continuous" pH data collected by USGS were above suspicion, they would be of little help to prompt enforcement: They are published only after months of delay, too late for timely corrective action.

In the Toledo area, at least, one may argue that entirely too much attention has been given to the quantitative standards, meager as even that has been. The rather general language of the "four freedoms" is adequate to deal with the gross pollution. Raw sewage (traceable to faulty regulators and overflows) is widely evident at least several times a week throughout the year, regardless of precipitation.

Decomposing sludge banks, well marked by gas bubbles and oil slicks, can always be seen around Promenade Park (RM 5), where Swan Creek and several large sewers regularly discharge raw, smelly, unsightly wastes. Oily sludge beds, composed of flocculants from the city's own waterworks and of refinery wastes, clog the lower reaches of Otter Creek. The mouth of Swan Creek (in the heart of downtown Toledo) is almost continuously septic during the summer, and is occasionally septic even in March and April; the stench can be overpowering in hot weather.

In short, the basic standards embodied in the "four freedoms" are sufficiently violated for any ordinary citizen to know that something is radically wrong with the water, and everyone knows that faulty waste collection and treatment are largely to blame. No measurements are required.

It is curious that one set of standards is applied to waters as diverse as the estuary (which never contains less than billions of gallons of water), to Otter Creek (whose flow is largely derived from wastewater discharges), to suburban Swan Creek and Tenmile Creek (whose dry-weather flow is scarcely more than a trickle), and to miscellaneous tributaries (such as Grassy Creek) whose flow is smaller still. The standards are rigidly uniform; the waters they apply to are non-uniform in every conceivable way: in quantity, in quality, in hydrology, and in actual uses. Surely, more should be expected of the estuary than of upper Tenmile Creek; and it is only reasonable to expect less of Otter Creek than of the lower Maumee. Perhaps there is something to be said for paying more attention to the waters themselves in setting WQS. There is certainly something to be said for examining the waters before using wasteload-allocation procedures that are hydraulically inappropriate and nearly data-free.[1]

---

[1] OEPA (May 1974) Op. cit.

4. SURVEILLANCE

The OEPA sets, implements, and enforces WQS, but it rarely conducts pollution surveys anywhere near Toledo. With two exceptions (see below), the State has never published its Maumee surveys, and such scanty data as it has otherwise collected are all derived from grab samples taken by OEPA's Northwest District Office in Bowling Green. The burden of surveillance is de facto carried by TPCA, whose data have only been used to fill a file cabinet, to our best knowledge: No one confessed to having seen them.

The State's two formal investigations into the water quality of the Maumee were published in 1953[1] and 1966[2] -- two surveys in over twenty years. Both reports concluded that the Maumee in Toledo is polluted. Anyone who had the courage to take a deep breath while standing on the little bridge at the mouth of Swan Creek during a dry week in August could have spared the State the trouble and expense of a survey. The U. S. FWPCA's 1966 report[3] arrived at the same unexceptionable conclusion. All three reports were on the entire Maumee basin, with no particular emphasis on Toledo; the broad coverage of these surveys may explain in part why the hydraulics of the estuary and the special pollution problems in Toledo (leaky sewers, large cooling-water discharges, etc.) got much less attention than we think they deserve. All the reports concluded that the basin's STPs must be upgraded to at least full secondary treatment: Not less than 85%

---

[1] Ohio Dep't. of Health (1953). Report of Water Pollution Study of Maumee River Basin, 1950-51. The Dep't., Columbus.

[2] Ohio Dep't. of Health (1966). Report on Recommended Water Quality Criteria for the Maumee River Basin. The Dep't., Columbus.

[3] U. S. FWPCA (1966). Report on Water Pollution in the Maumee River Basin. Available from the U. S. EPA's Cleveland office.

BOD removal at Toledo. U. S. EPA's 1966 report also recommended "maximization of phosphate removal" and major improvements in all the basin's sewers.

Several agencies routinely monitor the Maumee from Waterville (RM 21) down to Maumee Bay. The most comprehensive set of measurements is taken at Waterville by the USGS: daily discharge; continuous DO, pH, temperature, and conductivity; and grab samples -- varying from daily to monthly, but usually biweekly -- for various chemical, physical, and bacteriological analyses which change from year to year. The river is well mixed at Waterville (rapids and riffles extend from RM 30 to about RM 14.5), so there is no question of the samples' being distorted by stratification. The continuous measurements are, however, open to question. A field technician looks at the probes every two weeks, he wipes off the slime, and runs one Winkler titration to ascertain how far the DO readings may have drifted. He then uses this one titration to develop a "correction factor" for the past two weeks' readings. Though this is better than nothing, it can hardly be said that the probe is properly calibrated. Moreover, the ion-selective membrane and the electrode are rarely replaced: Maintenance is perfunctory, at best. We counsel extreme caution in using any data from USGS' continuous monitors in the Maumee. with a special warning about the DO readings. USGS data on daily discharge, stage, velocity, and sediments are indispensable, and of excellent quality. The grab samples leave something to be desired: They are not preserved (which invalidates all nitrogen measurements, at the very least), and they are sometimes stored for weeks before being analyzed (which invalidates nearly everything else). Even if these data were above suspicion, however, they would still be valueless for understanding conditions in the estuary, where the water is in large measure backflow from Lake Erie, altered by wastes from Toledo; moreover, it is difficult to understand how the Maumee's DO in the midst of a long riffle could have any significant bearing on DO in the comparatively stagnant estuary. These objections apply with equal force to pH, conductivity, and nearly all the chemical analyses. Samples from Waterville could, however, serve a useful function: They could be used to assess the size of the upriver heritage of pollution and the relative importance of point and area sources above Waterville.

The new Lucas County STP in suburban Maumee (near RM 17) began taking weekly grab samples above and below the STP outfall in 1973. Samples are collected within arm's reach of the riverbank, but since the river is still in riffle it is probably well mixed (it would be prudent to confirm this at very low flow with well-calibrated conductivity, DO, pH, and temperature meters). No allowance is made for time of travel between the upriver and downriver sites, and all samples are taken near midday. Analysis is begun immediately, and no short-cut methods are used.

The TPCA has by far the largest store of WQ data on the lower Maumee and its tributaries. Monthly grab samples have been collected at several dozen stations since 1966-67. Most (but not all) of the customary WQ analyses are conducted: bacteria, ammonia, nitrate, nitrite, chlorides, total phosphorus, pH, conductivity, DO, temperature, 20°-BOD_5, Jackson turbidity, dissolved solids, and suspended solids. Among the most important of the missing analyses are COD, TOC, total carbon, dissolved phosphorus, Kjeldahl nitrogen, long-term BOD, oils and greases. All samples are collected during normal working hours, near shore, and just below the water surface. Sampling an estuary is much more complicated than sampling a riffle: Methods that are perfectly acceptable at Waterville or Maumee cannot be used in Toledo because the water and its behavior are entirely different. The river may be stratified both horizontally and vertically: Samples taken near the shore and near the surface cannot begin to give an adequate picture of any estuarine cross-section; furthermore, no one cross-section can give an adequate picture of the entire estuary because there are major longitudinal differences between RM 14 and the mouth. Because estuarine currents are extremely unstable and subject to frequent reversals -- often several times a day -- monthly grab samples are impossible to interpret; daily grab samples would be no better. The flow reversal may be violent. For example, after a powerful estuarine flush the lake may rush upriver, shoving billions of gallons of lake water into the estuary in less than an hour. Water samples taken during mighty reversals tell nothing about the river (strictly speaking) or Toledo's effects on it. The estuarine hydraulics confound all grab samples; monthly grab samples in any of the estuarine waters around Toledo are essentially useless. If the water looks exceptionally clean, it is probably a recent addition from the lake; if it looks exceptionally polluted, the cause could be anything from a nearby spill or a leaky sewer to a long interval of estuarine stagnation -- quite a range of choices. TPCA's laboratory begins analysis soon after the samples are taken, but (as in most of the other laboratories) quality control is skimpy and some shortcut methods are used (e.g. Hach reagent pillows are used in nitrogen analyses).

Toledo's STP at Bay View Park (RM 0.7) analyzes monthly grab samples above and below the outfalls. The customary analyses are done in the usual way. No attempt is made to account for the unstable water mass, even though flow reversals destroy the distinction between "upriver" and "downriver"; indeed, samples at RM 0 ("downriver" from the STP) are quite likely to be much cleaner than samples taken at RM 1 ("upriver" of the STP outfall). The STP's discharge is usually about 100 mgd, and rarely more than 200 mgd; but this is as nothing compared to the enormous volumes of water that surge into the estuary whenever western Lake Erie rises.

USGS has a continuous monitor for DO, pH, temperature, and conductivity a few feet from the west bank of the river's mouth. The intake is a few feet away from the Coast Guard slip, whose waters we found (in September 1974) to be seriously degraded, and quite unrepresentative of conditions elsewhere at the Maumee's mouth. Horizontal and vertical stratification, which are more likely at the mouth than at any other point in the estuary, distort all data from this monitor. Furthermore, the river is less than 10 feet deep at the intake, whereas the mouth is more than 25 feet deep nearly everywhere else. In short, the monitor is ill-placed. Calibration and maintenance are, as at Waterville, unsatisfactory. In any event, the device is often out of service: It was completely out of commission from December 1973 to May 1974, and was down again during parts of August and September. Grab samples have been taken at this station from time to time, but they cannot give an undistorted picture of conditions at the mouth: The station is too near the polluted waters of the Coast Guard slip, it is at the point where the river is most probably stratified, and it is in exceptionally shallow water; furthermore, sample preservation and storage are deficient.

The U. S. Army Corps of Engineers, in cooperation with the U. S. Lake Survey, maintains a stage-height gage next to the USGS continuous monitor. The records are nearly complete. Two stilling wells are maintained; the second well is a backup. The wells are mucked out weekly, and for good reason: There is plenty of muck and trash in the Maumee to obstruct the wells' intakes, thereby interfering with the free flow of water which is essential for valid stage measurements. Between cleanings, the stage measurements may not be entirely reliable. Stage records are of the utmost importance in verifying flow reversals and estuarine flushes (see chapter 7). To document the estuarine dynamics, it will be necessary to install several more gages at intervals of three to five miles between the mouth and RM 14. Stage readings every fifteen minutes throughout the estuary's length must provide the fundamental data for depicting the powerful surges that travel up and down the river as the flow reverses. Thorough understanding of these positive and negative waves is a prerequisite for developing discharge rating curves for the lower Maumee River; several years of data will be required.

These various water-data programs lead independent lives, and most of the agencies are only dimly aware of the others' existence. No one tries to coordinate sampling schedules, to standardize analytical protocols, to split samples for analysis, to improve quality control in the laboratories, to pool resources, to share the cost of decent surveying equipment (boats, Kemmerer-type samplers, current meters), or even to inform OEPA of WQS violations.

That monthly grab sampling and continuous monitors leave a great deal of nastiness undetected and unaccounted for can be confirmed by simply walking along the banks of the rivers and creeks in Toledo. No equipment is required: One needs no more than normal vision and a not-too-delicate nose. Many of the "four freedoms" are violated almost all the time, but not necessarily at the points where grab samples are routinely collected, or in ways the usual water analyses reveal. For example, the lower reaches of Swan Creek were continuously septic during the last ten days of August 1973. We traced the problem, using the powerful stench and the unambiguous latex evidence, to several of the malfunctioning overflow regulators on the combined sewers that discharge to Swan Creek; we did not bother to trace the raw wastes above the Hamilton-Newton regulators, though there was still some latex evidence several yards upstream -- perhaps pushed upstream by reverse flow in the estuary, perhaps the heritage of other leaky sewers upstream. The 60-inch sewer outfalls at Jefferson Avenue and at Monroe Street (near Swan Creek's mouth) were also discharging raw waste, including a thick film of reddish oil. The regulators were plainly malfunctioning because there had been no rain at all for more than a week. This surprising observation led us to check five more of Toledo's several dozen regulators, and all were malfunctioning, as anyone could plainly see. Only one of the misbehaving regulators was known to TPCA. Failure to smell the raw sewage at the mouth of Swan Creek, or to see the oil slick at Jefferson Avenue, is particularly curious, since TPCA's offices are directly across the river, scarcely 300 yards away.

Among the most interesting WQS violations can be found in lower Otter Creek, which discharges into Maumee Bay about 0.75 mile ENE of the mouth of the Maumee River. This quite minor tributary to the bay flows through an area dominated by giant oil refineries, tank farms, chemical plants, railyards, and dock facilities. On the several occasions we walked along the creek in August 1973 we were impressed with the general cleanliness of the area and with the complete absence of oil slicks. However, a large stretch of the creek is choked with fine solids, which we traced to Toledo's water-filtration plant; flocculants and settleable solids are discharged from the waterworks to both Otter Creek and Duck Creek, and the gray turbidity contrasts vividly with the water just upstream. The discharge of solids by the waterworks is chronic, as the choked streambed shows; on the several occasions we inspected the waterworks' outfalls in 1973-74, they were always very turbid. We find it odd that the most visible pollution of little Otter Creek, surrounded by heavy industry, should be the city's own waterworks.

Discharges into either Otter Creek or Duck Creek (and to the lower reaches of Swan Creek) are difficult to understand, since the river and the bay are so near. Why not discharge to a much larger body of much greater assimilative capacity? This question occurred to us again in our winter (1973-74) inspection tours of Otter Creek. The effluent from SOHIO's secondary treatment plant (near the creek's mouth) covered the creek with a cloud of acrid steam; fog-warning signs were posted along Otter Creek Road. The objectionable odor is certainly well above the odor standard: "The threshold-odor number attributable to human activities shall not exceed 24 at 40 degrees centrigrade".

A pebble casually thrown into the water below SOHIO's outfall reveals another violation: An oil slick rises to the surface immediately; this same result may be obtained all the way to the mouth of the creek and into Maumee Bay. (We learned during our brief sediment survey -- see chapter 8 -- that the concentration of oils and greases at the mouth of the creek is nearly 13,000 mg/kg, on a dry-weight basis; there are several places in the river and near the mouths of small tributaries where the concentration of oils and greases exceeds 5,000 or even 10,000 mg/kg.)

In weighing this evidence, however, it is well to bear in mind that Otter Creek is as much an artifact as it is a work of Nature. During droughts the creek would be nearly dry were it not for the industrial discharges. It is not affected by these discharges: It is these discharges. Is it an open sewer? Yes and no. Although the discharges (over 40 mgd) make up most of the dry-weather flow, and although the creek's mouth was moved from the river to the bay long ago, Otter Creek is a natural watercourse. Furthermore, it flows through Navarre Park and Ravine Park. If the industrial discharges are rerouted away from the creek, the aquatic life will be spared chemical wastes, but it will also be deprived of water during quite minor droughts; dry streambeds are "toxic" to fish, algae, and even sludgeworms. We offer without formal proof the assertion that very high degrees of treatment -- far beyond BAT -- would be required to meet WQS for fishlife in Otter Creek; moving the discharges to the river or the bay would no doubt be cheaper and easier. But once the discharges are moved, the creek will often be dry: no water, no fish. Neither alternative is attractive, and neither promotes aquatic life.

Perhaps it is worth considering some use for Otter Creek other than "for warm water fisheries, for primary contact recreation, for processing by conventional treatment into public, industrial, and agricultural water supplies".[1] Under the current standards for low-flow streams, Sun Oil's discharge would be permitted to continue with no more than BAT, because the upstream drainage area is less than five square miles; but SOHIO's discharge would not be permitted to continue unless WQS could be met: The upstream drainage area is too large. To satisfy the policies (though fish may never know the difference), SOHIO must move its discharge to the river or the bay; Sun Oil and the waterworks must continue their discharges to maintain the streamflow. Perhaps policies that require such perverse logic should be reconsidered. Among other oddities, SOHIO discharges to the creek's estuarine reach, where there is always plenty of water; in dry weather, however, Otter Creek is dry above the industrial discharges and lagoons. There is, however, a simple solution to this quandary: Change the definition of a low-flow stream's drainage area from five square miles to ten or twenty-five square miles -- the number is arbitrary, and almost any reasonably small number could be defended.

After observing how frequently the city's regulators malfunctioned during a summer drought, we were keen on seeing what happened in cold weather and in rain. A brief inspection during early December 1973 provided a perfect set of conditions. The weather had been dry and bitterly cold for nearly a week. Although Swan Creek no longer stank of sulfide, we had no trouble finding the telltale latex evidence, and traced it once again to malfunctioning regulators. A day later the weather turned to mixed snow and rain. We quickly went to the mouth of Swan Creek and the large sewer outfalls into the river at Jefferson Avenue and its neighboring streets. Within a few feet of the Jefferson outfall we found an assortment of floating debris and a heavy scum of thick, black, oily sludge which hugged the west bank of the river along Promenade Park before it gradually spread out into the navigation channel, where it was joined by similar overflows from the sewers at Madison Avenue, Adams Street, and Jackson Street.

---

[1] OEPA (27 July 1973). Water Quality Standards. EP-1-01 (A).

After every heavy rain Swan Creek flushes a heavy black plume into the Maumee River. The plume is quite visible from Promenade Park; those with a taste for comfort and luxury can see it (along with the plumes from the sewers) from the elegant restaurants atop the Holiday Inn and the Fiberglas Tower. These flushed sediments introduce "substances attributable to human activities which result in sludge deposits, floating materials, color, turbidity, or other conditions in such degree as to create a nuisance."[1] Although a natural phenomenon (heavy rain) flushes the filth, "human activities" create it. There is something to be said for a sediment-quality standard.

Toledoans have few misconceptions about the city's poor sewers, nor does the OEPA. The many fishermen who gather at Promenade Park suffer the fewest misconceptions of all, especially those who fish at the Jefferson Avenue outfall; the only mystery is, knowing what they know, how they can eat what they catch: Many don't. The only serious analysis we have seen of Toledo's sewer problem is a report, not by OEPA or TPCA, but by a private consultant to a citizen-action group.[2] Although the Earthview report is not perfect (it ignores, for example, the readily observable fact that the regulators often bypass raw sewage even during long dry spells), it is a detailed, thoughtful piece of work and deserves a careful reading.

---

[1] OEPA (27 July 1973). Water Quality Standards, EP-1-02 (L).

[2] EARTHVIEW, INC. (February 1973). Combined Sewer Pollution -- City of Toledo: Report of Investigation. Prepared for Voices for Environment, Inc., Toledo. Available from George R. Kunkle, President, Earthview, Inc., 316 Colton Bldg., Madison and Erie, Toledo, Ohio 43624.

Much is not known about the Maumee, but some things have been learned through decades of surveillance. It is remarkable, then, that OEPA's wasteload allocation is so riddled with unknowns (UK in their simple form).[1] Among the UKs are: average flow at Waterville and SS concentration at average flow; temperature, DO, BOD, SS, fecal coliform, ammonia, and Kjeldahl N at Waterville low flow. USGS' annual summaries and the 1966 pollution reports by the Ohio Health Department and FWPCA have answers to these UKs. One can't guess why OEPA marked the average Waterville flow UK. Many entries that aren't UK are wrong. E.g., the total water input below Waterville is not 3.0 cfs: STP discharges from Toledo and its suburbs must be included, since the area's water supply comes from Lake Erie; Toledo's STP alone always discharges over 100 cfs. When OEPA lists WQ values for both low and average flow, they are always identical; even the pH is invariant. Many of these values are attributed to USGS data, but one doubts that USGS could have drawn such conclusions from its years of work at Waterville and at the Coast Guard Station. See table 6-1 (pp. 55-57) for a fuller listing of USGS' Waterville data.

The most curious feature of this wasteload report is its hydraulic inappropriateness: The lower Maumee is treated as though it were a free-flowing stream, whereas it is in fact a large estuary -- indeed, the largest estuary in Ohio or in Lake Erie. The low flow at RM 0.4 cannot be 71.7 cfs (the .7 is quite a touch); because of reverse flow, the true value is undoubtedly a very large negative number (on the order of minus 100,000 cfs), though no one will know precisely until the estuarine hydraulics have been carefully studied for several years. Insofar as current policies and practices do not distinguish estuaries from streams, they must be changed. Every stream emptying into Lake Erie, not just the Maumee, is estuarine near its mouth.

---

[1] OEPA (May 1974). State of Ohio, Maumee River Basin Waste Load Allocation Report for the 303(e) Continuing Planning Process for Water Quality Management. Draft. Section 5. Undated, unpaginated.

The overlooked 1966 reports by the Ohio Health Department and the U. S. FWPCA contain -- in addition to fundamental information on hydrology and waste dischargers, and much wisdom on the importance of area sources well above the estuary -- valuable measurements of water quality during the hard drought of the early and middle 1960's. Their observations at Waterville are especially important, since the USGS monitor is not trustworthy. FWPCA reported that during October 1964 - June 1965

> "diurnal DO studies showed considerable vertical and diurnal variations. Values as high as 10 mg/l were often found at the surface while the bottom waters contained only 0.5 mg/l. Diurnal variations gave early morning concentrations of 8.0 mg/l at the surface and 25 mg/l in the afternoon. The low DO values at the bottom confirmed the absences of any intolerant animals on the stream bottom." (p. 7-11)

On 21 July 1964, they observed a minimum DO of less than 5 mg/l just before dawn, and a maximum of nearly 16 mg/l at midday.

The Health Department's report includes graphs (figures 15a and 15b) of diurnal variations in pH and DO at Waterville for 27 - 30 September 1965. During this interval, DO ranged from 5.0 mg/l (at midnight on 30 September) to 13.5 (in early afternoon, 29 September); diurnal variation was always more than 5 mg/l. The pH also showed large diurnal variation, usually 1.5 units, and ranged during this interval from 6.5 (at dawn, 27 September) to 9.2 (during the early afternoon, 30 September). Both the DO and pH variations were attributed to intense photosynthetic activity by algae.

Assuming that the continuous monitors which provided these measurements were correctly calibrated, one must conclude that both the pH and the DO at Waterville -- where the river is in riffle -- violate even the most permissive WQS ever established for the Maumee. During our 1974 surveys of the turbid estuary, we never observed so much as 1.0 mg/l diurnal variation in DO; but 1974 was a much wetter year than either 1964 or 1965, and lake levels were much higher. However, we often found DO less than 4 mg/l; no doubt, the estuary's DO in 1964-65 must have been much lower. If, owing to algal metabolism, the Maumee cannot meet DO and pH standards at Waterville (where the river is reaerated by relatively swift flow over a long, rocky riffle), what hope is there for the quiet estuary's meeting standards? Will the standards be violated in times of drought and low lake levels even if Toledo overcomes all its waste-management problems? Would they be violated at such times even if there were no Toledo? Are the standards unrealistically high? These are uncomfortable questions, and we can offer no answers. But they are worth thinking about. Improved surveillance in the years to come may resolve all doubts.

5. TOLEDO'S SEWERS AND THE NEW STP

The quantities of sewage and oil we saw bypassed from Toledo's sewers at all seasons, in wet weather and in dry, prompted us to look into Toledo's sewer controls. After all, a great deal of "point source" waste never gets to the new secondary treatment plant, and might as well not be collected.

In addition to sizable leaks and bypasses, the sewers are subject to infiltration and inflow. The magnitude of infiltration and of inflow from combined sewers can be judged from the STP's data on the volume and conductivity of the raw wastes which do get to the plant. In May 1974, over four inches of rain fell on Toledo; over 1.5 inches fell during the week of 6 May. Inflow volumes during this week ranged from 98.65 mgd to 149.90 mgd, and the peak volume coincided with the day an inch of rain fell (8 May). The influent conductivity fell from 870 micromhos on 7 May to 550 micromhos on 8 May; that month, influent conductivities ranged from 550 to 890 micromhos. September 1974 was much drier: The total rainfall for the month was 1.4 inches, and the previous two months had been very dry. During 18-25 September, inflow volumes at the STP were 63.72 - 77.92 mgd; less than 0.2 inch of rain fell during that interval. Influent conductivities, however, ranged from 590 to 860 micromhos, and zoomed to 910 on 30 September.

The difference in influent volume (September versus May) is nearly 80 mgd at the extreme, and is generally about 25 - 30 mgd. The large fluctuations in influent conductivities suggest that there is more variation than can be attributed to rainfall alone: The peak conductivity of 910 on 30 September is unrelated to any climatic event, and is over 50% higher than the influent conductivity of 590 on 19 September. In addition to infiltration and inflow, there is strong evidence of industrial wastes being dumped into the sewers, perhaps in larger quantities than the city knows about. After investigating the sewer permit program, we are persuaded that there is very little knowledge of, or control over, industrial taps into the sewer lines. Paradoxically, governmental policy at all levels now encourages even more industrial hookups, and requires more municipal control over them, than ever before.

Interlake's steel and coke plant provides a useful example. Interlake has abolished one of its outfalls, and sends these wastes to the STP, through the city's sewers, instead of building treatment works for itself. (Despite a good deal of paper to the contrary, all our informants in the program told us that the STP will accept any industrial discharge so long as it is not so acid as to corrode the pipes.) Well and good; but in view of the fact that the regulator which governs the interceptor and sewer #783 (Interlake's sewer taps) malfunctioned during several of our inspections, one must conclude that some of Interlake's wasteload was discharged to the Maumee without any treatment at all, save admixture with other wastes in the sewer lines. Is this the kind of treatment Interlake pays the city for?

In an attempt to learn more about industrial hookups we asked TPCA for a list. They confessed they had none, but sent us to the STP's Chief Chemist, whose office would have the official list, we were assured. We were not assured when the STP told us it had nothing of the kind, and that TPCA kept such lists. Upon breaking the sad news to the STP, we were sent off to Toledo's Sanitary Engineer, who must certainly have the list, we were told. He didn't, and was taken aback to learn that neither TPCA nor the STP has it. The situation seemed hopeless to him, but he sent us to Toledo's Division of Construction and Engineering, where we would have to check the city's sewers maps and sewer permits, one by one.

Each sewer connection requires a permit, but there is no index by permittee. To locate the permit, one must know precisely where the industry is, be able to find it in a very much out-of-date atlas of sewer maps (e.g., Interlake is still called Toledo Furnace on the maps -- a name it has not had for decades), and take down the number of each nearby sewer line the plant might have tapped into. One then consults a card file for each sewer number, and searches through a chronological and often illegibly handwritten list of antiquated names to learn whether the city knows of any hookup credited to the suspect industry. If the city does know, a unique permit number is assigned to each hookup. One must now consult the permit file, which, judging by the dust deposits, serves a purely archival function. It is easy to understand why the files are not used more: They were designed for storage rather than retrieval; moreover, many of the permits were granted and filed away long before people worried much about pollution of the lower Maumee and Lake Erie.

The permit is a standard form which shows on a small map where the connecting pipe will run. There is no chemical analysis, nor even mention of whether the hookup is for sanitary wastes, process water, "housekeeping" water, or any combination thereof. The fact that the permit system is not used can be judged by more than its inherent encumbrances, its thick surficial deposits of bureaucratic dust, or the exiguous information in it: Its contents are sometimes hopelessly inconsistent or just plain wrong. For example, in the small sample (less than 100 industries) we examined, Doehler-Jarvis' permit (County sewer #155-17) plainly showed a tap into the sanitary sewer, but the permit itself was boldly marked "STORM" in large letters; this discrepancy, which no one could explain, suggests that Doehler-Jarvis is sending its stormwater runoff via the city's sanitary sewers to the STP for treatment. From what is known about Toledo's faulty regulators and the hydraulic limitations of both its sewerage and its STP, chances are that the stormwater will never be treated. There are other oddities. One ten-block section of downtown Toledo shows no sewer lines at all: Can one believe that a large tract of the commercial district depends on privies for sanitation? One assumes that the sewer atlas is deficient.

The emphasis by State, Federal, and local agencies on treatment plants is partly to blame for the serious neglect of sewerage and waste collection. The consequences of this policy, as we observed them in Toledo, are poorly documented sewers, no real control of what goes into (or leaks out of) the sewers, grossly malfunctioning regulators, and fascination with theoretical STP effluents at low river flows, rather than with the wasteloads which actually enter the estuary at all times of the year. Scant wonder that the Maumee River in Toledo usually violates WQS.

The importance of sewerage has not been entirely lost on OEPA and its predecessor agencies; unfortunately, they have emphasized new construction and sophisticated technology rather than efficient maintenance and operation. OEPA's 1972 permit to the Toledo STP ordered, inter alia, that the city submit plans for a pumping station, a force main, an interceptor, and lateral sewers in certain suburban areas; that the city place "under construction by December 1, 1972, the proposed telemeter-sensing system in the regulators of the combined sewer system" (as of mid-1974, the city had awarded a $10,000 study contract to investigate the preliminary feasibility of the telemetering system, which is not the same thing as having begun construction more than a year earlier); and that OEPA be immediately informed of any raw or partially treated municipal wastes discharged "due to sewer breaks, equipment malfunctions, or failures, construction schedules, and/or plant shutdowns." These "orders" can be hardly more than little black words on white paper. If Toledo kept OEPA abreast (immediate reports, by "telephone or telegram") of all incompletely treated discharges from the sewers and the STP, OEPA's phone would be busy most of the time. The fancy "telemeter-sensing system" is still paper, not hardware; a good sewer inspector or two would probably be a wiser investment, especially if he came equipped with normal vision and a decent nose for raw sewage.

Excluding thermal discharges, the largest wasteloads by far from any point source on the Maumee River come from Toledo's own STP, which is located in Bay View Park, on the river's west bank, about half a mile from the river's mouth. Growing alarm over pollution of Lake Erie roused the city to build a modern secondary plant with phosphate-removal facilities -- not without pressure and financial aid from the State and the Federal Government. The final demonstration-testing was conducted in 1974, though the secondary plant has been in operation for some time.

The new STP is a touchy issue, in part because Toledo has spent $20 million of Federal, State, and local money during the past decade to expand and modernize it. The plant's designer is quick to point out that the new facilities usually achieve nearly 90% BOD removal; it may further be added that there are many days when the plant produces a 20/20 effluent, or even better. Nonetheless, there are difficulties, and the plant's performance is sometimes shocking. Tables 5-1 and 5-2 summarize the STP's performance during our May and September 1974 surveys; all the analyses were performed by the STP itself. The September data (table 5-2) suggest how badly the STP can perform, nor is this an isolated instance. Some put most of the blame on poor operation and maintenance of the new facilities. STP personnel, while readily admitting that operation and maintenance leave much to be desired, plead that many of their difficulties stem from the plant's faulty design.

We take no stand on this issue, and defer to the Toledo Metropolitan Area Council of Governments, whose report on waste management in northwestern Ohio and southeastern Michigan will weigh these rival claims. We can report that something is seriously wrong, whatever the cause. We also invite attention to the fact that under current policies, pollution-control requirements are designed around the 7-Q-10 of the river (i.e. the droughtiest week that is likely to occur in a decade) -- even in estuarine segments. Fair enough, but perhaps STPs should be judged by their worst performance too (e.g. the poorest week's performance each decade). If the Maumee's waste-assimilative capacity is to be judged by its actual 7-Q-10 of less than 80 cfs, perhaps Toledo's waste-discharge capacity should be judged by the STP's actual performance in September 1974 -- several months after it was officially inspected (and approved) for an NPDES permit, and several months after final demonstration and acceptance testing. Why shouldn't STPs be judged by the same statistical criteria as rivers?

The STP's deplorable performance in late September is due to spills of solids. The gravity of the spill may be judged from the fact that the STP receives the wastes from about 500,000 people; each person contributes about 0.2 lbs of suspended solids daily in raw wastes, and about 0.17 lbs of BOD, on the average. The STP's effluent SS on 18 September is equivalent to the raw wastes of over two million people -- four times Toledo's actual population. The STP's effluent BOD on 18 September was considerably higher than the influent BOD load. In reading tables 5-1 and 5-2, it should be borne in mind that if the STP worked properly, the effluent BOD should not exceed 8,000 lbs/day, and the effluent SS should not exceed 10,000 (based on 90% removal, standard P.E., and a contributing population of 500,000). During our two surveys, the STP approached the target BOD efficiency only on 8 May, when the effluent BOD was 8,260 lbs; in neither survey did it even approximate adequate SS removal. In judging phosphorus removal, recall that each person contributes about 5 grams of total phosphorus in his daily raw wastes; at 85% removal efficiency, the STP should not discharge more than 825 lbs/day. Only on 7 and 10 May did the STP get anytning approaching these removal efficiencies. Plainly, something is wrong.

Close examination of tables 5-1 and 5-2 brings to light several curiosities. For example, effluent SS concentrations on 24 September were nearly ten times higher than SS concentrations on the 23rd; yet ammonia concentrations were much lower on the 24th than on the 23rd. It is not at all clear how the plant could have been passing vastly more solids while at the same time passing so much less ammonia; nor is it clear why phosphorus loads on the 24th were so much lower than on either the 23rd or the 25th, in view of the SS loads on those days. The discrepancy between SS removal and P removal is also evident on 6-7 May. Such behavior cannot be readily explained, and leads one to suspect the analytical data. Plainly, something is wrong.

The STP's personnel readily volunteer examples of design features which vex their work, they say. Here is one illustration that is easily grasped. The new plant retains the design of the radial skimmers which remove oil and froth from the surface of the primary settling tanks; there are several banks of them. These skimmers, which operate much like the second hand on a watch, are installed in square -- not circular -- tanks, which makes for muck in the corners. Rather than changing the shape of the tanks in the new plant, or (better still) installing a skimmer which would sweep over the supernatant liquids like an edge-to-edge windshield wiper, with a scum box at each end of the traverse, a fascinating contrivance was preserved. Each skimmer arm is equipped with telescoping joints which expand the arm for the square corners and contract it for the tangents. This system works none too well, and the weight of the telescoping joints puts too much stress on the arms, which are apt to slip, sag, or stop. For whatever reason, there were important items of equipment out of service during many of our visits to the STP. Plainly, something is wrong.

Equally plainly, something has been wrong for some time, though the causes are various. In April 1973 (as reported in the Toledo Blade of 4 April 1973 and the Toledo Times of 5 April 1973, both stories on

TABLE 5-1

TOLEDO STP DATA: 5-12 MAY 1974

Source: Unpublished STP Records

Date	Effluent Q		20°-BOD$_5$		SS		Total P		Ammoniacal N		Nitrite N		Nitrate N	
	mgd	cfs	mg/l	#/d	mg/l	#/d	mg/l	#/d	mg/l	#/d	mg/l	#/d	mg/l	#/d
5 May	88.16	136.38	--	--	--	--	--	--	--	--	--	--	--	--
6 May	100.72	155.81	18	15,138	24	20,184	1.63	1,371	--	--	--	--	--	--
7 May	98.65	152.61	18	14,827	80	65,898	1.04	857	--	--	--	--	--	--
8 May	149.90	231.90	10	12,517	24	30,040	1.28	1,602	14.1	17,648	0.106	133	0.09	113
9 May	109.16	168.87	19	17,318	27	24,610	2.42	2,206	--	--	--	--	--	--
10 May	109.92	170.05	9	8,260	21	19,274	0.94	863	--	--	--	--	--	--
11 May	117.42	181.65	--	--	--	--	--	--	--	--	--	--	--	--
12 May	110.67	171.21	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 5-2

TOLEDO STP DATA: 18-25 SEPTEMBER 1974

Source: Unpublished STP Daily Records

Date	Effluent Q		20°-BOD$_5$		SS		Total P		Ammoniacal N		Nitrite N		Nitrate N	
	mgd	cfs	mg/1	#/d	mg/1	#/d	mg/1	#/d	mg/1	#/d	mg/1	#/d	mg/1	#/d
18 Sept. '74	74.47	115.21	172	106,954	682	424,084	8	4,975	14.3	9,250	0.198	123	0.162	101
19 Sept. '74	77.46	119.83	98	63,386	356	230,258	24.1	15,580	--	--	--	--	--	--
20 Sept. '74	77.28	119.55	41	26,457	100	64,529	13	8,389	11.4	7,356	--	--	--	--
21 Sept. '74	69.18	107.02	--	--	--	--	---	--	--	--	--	--	--	--
22 Sept. '74	63.72	98.57	--	--	--	--	---	--	--	--	--	--	--	--
23 Sept. '74	77.92	120.54	28	18,218	28	18,218	3.4	2,212	11.6	7,547	--	--	--	--
24 Sept. '74	73.98	114.45	99	61,156	232	143,314	1.90	1,174	8.9	5,498	--	--	--	--
25 Sept. '74	73.66	113.95	109	67,042	232	142,694	4.20	2,583	10.0	6,151	0.24	148	2.74	1,685

page one), the problems of the new STP literally erupted. The coupling on a pipe, 15 feet below ground, exploded, and tore a fist-sized hole in a pipe which connects two sections of the plant. Sewage sludge and carbon monoxide spewed out of the pipe, and began filling a 30-foot maintenance chamber below ground level. The STP was closed down for several days; during this time all sewage was discharged to the river without treatment of any kind. The load was approximately four million gallons an hour. To reduce hydraulic pressures on the STP, regulators were opened all over town, thereby disgorging raw sewage all along the Maumee, the Ottawa River, and Swan Creek. Not six months earlier, the STP dumped 186 million gallons of raw sewage into the Maumee during the floods of November 1972. In routine inspections, the U. S. EPA noted nine major construction defects in November 1972, and again in February 1973; EPA reported that design deficiencies could conceivably cause a shutdown of the main pumping station, which would put the entire plant out of service. The only way the city fathers had to deal with these emergencies was to beg the citizens to curb their water use.

The explosion in April 1973 was dramatic enough to have made the headlines. The plant's designer admits that this explosion was serious, but argues that it was only a normal accident such as might befall any major engineering project: After all, the culprit was a pipe that had been improperly anchored during construction. The more serious malfunctioning during late September 1974 escaped wide attention. The competition among deficiencies in design, construction, and operation in accounting for the STP's extremely variable performance deserves a most careful, impartial judge. We can only report that something is plainly wrong, and that the issue is extremely touchy.

6. AREA SOURCES AND THE UPRIVER HERITAGE

Toledo is unquestionably a major polluter of the estuary, the bay and their tributaries; but what can be said about the cities, industries, and rich farmlands further up in the drainage basin? Some important clues can be found in the sediments which have accumulated in the estuary and the bay. Other signs can be found in the fluxes (flowing loads) of solids and nutrients at Waterville (RM 21), which is above Toledo, but below nearly all other point and area sources.

The earliest charts of the region, prepared by the U.S. Bureau of Topographical Engineers,[1] show that the bay was very shallow (usually 10-11 feet, and never more than 15 feet) and that the tortuous channel of the estuary, though sometimes deeper than 20 feet, was blocked by large bars of clay, mud, and sand. The erosive forces of Lake Erie on the soft lands which border it have progressively enlarged Maumee Bay; at the same time, the slow subsidence of northwestern Ohio (about nine inches in the last hundred years) has further drowned and enlarged the river's lacustrine estuary. In order to maintain the busy navigation channel through the bay and the estuary, the Corps of Engineers annually dredges about 1.5 million cubic yards of sediment from Toledo harbor. The Corps has reported[2] that the bay accumulated two feet of sediment during the last century. According to the Corps' estimates, the Silurian-age dolomites of Erie's western basin are overlaid by at least 100 feet of glacial till -- predominantly stiff to extremely stiff silty and plastic clays; above these heavy clays is a 10-foot deposit of geologically recent materials. Close to the river's mouth these recent deposits are soft and spongy, with a high content of organic matter. This organically loaded clay may be observed everywhere from Ewing Island (approximately RM 13) to Cedar Point (at the bay's eastern extreme).

---

[1] The earliest of these was prepared by Capt. (later Gen.) George G. Meade in 1844: Maumee Bay -- Survey of the Northern and North Western Lakes. U.S. War Dept., Bureau of Topographical Engineers.

[2] In an unpublished 1973 report to John A. McWilliam, General Manager of the Toledo-Lucas County Port Authority, from Col. Myron D. Snoke, Detroit District Engineer.

The Maumee is laden with salts and silt. When it is in spate, it commonly carries one ton a day of sediment for each cfs of discharge: At 35,000 cfs, its daily sediment load is about 35,000 tons (see figure 6-1). Most years, one to two million tons of sediment flow past Waterville; this amounts to over 150 tons annually eroded from each square mile of the basin, and is not untypical of Eastern rivers. Because these sediments are organically enriched, one should suspect that they are something more than innocent clays.

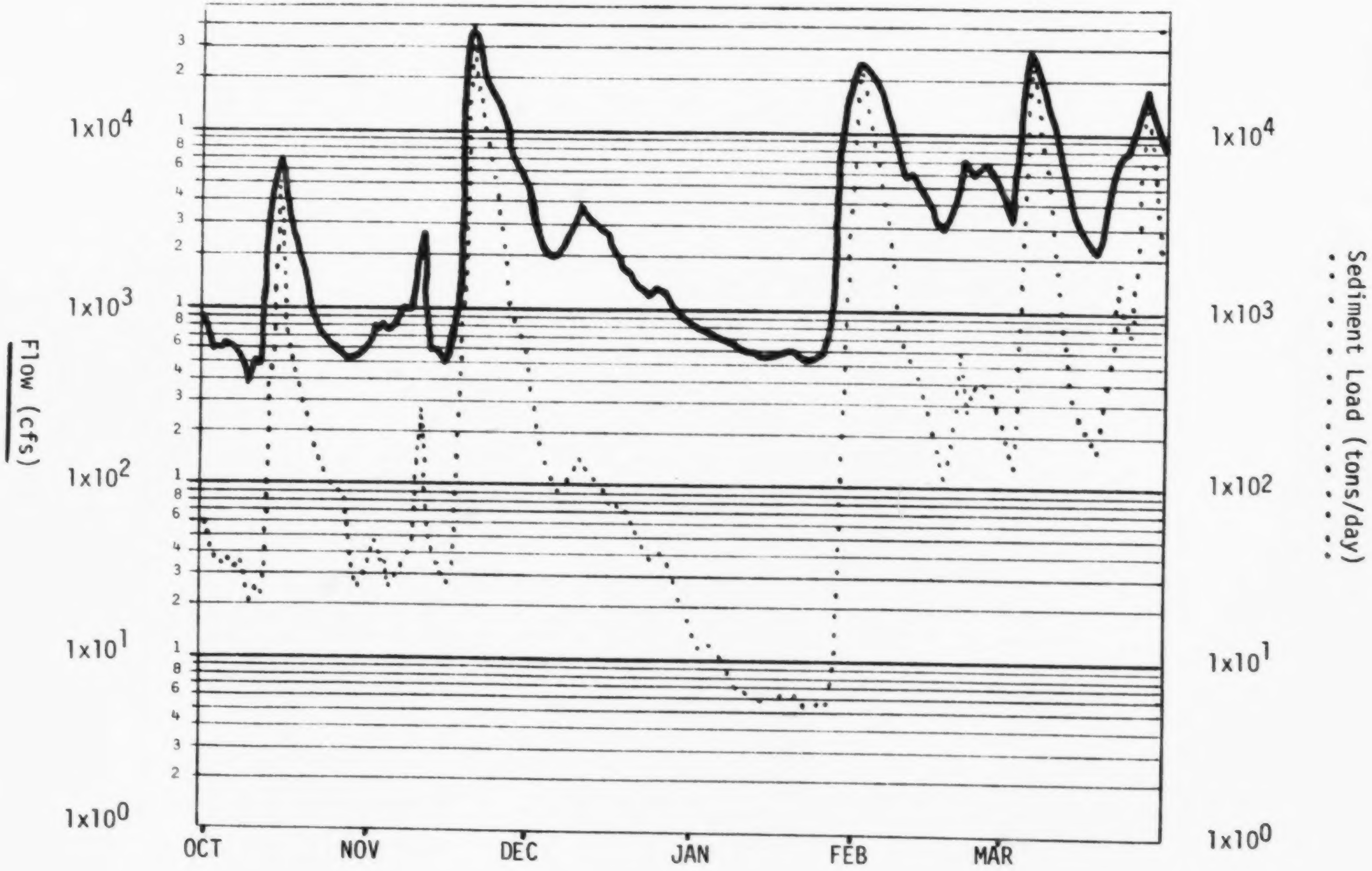
These suspicions are further strengthened upon considering phosphorus fluxes at Waterville. In general, when the Waterville discharge is high, the phosphorus flux is high, and when the discharge is low, the flux is low. At discharges greater than 20,000 cfs, the river commonly carries over 25 tons of phosphorus a day past Waterville. The close relation between discharge and flux is persuasive evidence of landwash effects and area sources: There is no reason to believe that cities and industries discharge more nutrients in wet weather than in dry, but there is every reason to believe that more soil and fertilizer are eluted from farmlands in rainy weather than in drought. This pattern is not peculiar to the Maumee: It has been observed in many other rivers, and has been particularly well documented by Baker and Kramer[1] in the nearby Sandusky River basin. The peak phosphorus fluxes

---

[1] DB BAKER & JW KRAMER (1973). Phosphorus sources and transport in an agricultural river basin of Lake Erie. Proc. 16th Conf. Great Lakes Res. 1973:858-71.

Figure 6-1.

Flow and Sediment Loads at Waterville (USGS #04193500):
October 1969 - March 1970



of over 25 tons a day cannot be explained by any of the point sources upriver. The total population upriver of Waterville is approximately 800,000. Assuming no phosphorus removal at all by the upriver STPs, and assuming five grams of phosphorus per capita per day in the raw wastes, we can account for less than five tons a day of phosphorus flux.

These same arguments apply with equal force to other fluxes. Suspended solids, for example, may exceed 100,000 tons a day at flood peaks (see Figure 1-1). Again assuming 800,000 population above Waterville, and assuming 0.2 pound of suspended solids per capita per day in the untreated wastes, we can account for no more than 80 tons of the flux. Point sources fall very far short of explaining the river's behavior; in wet weather, the point sources (even assuming the worst about them) explain almost nothing at all.

Nearly every WQ component at Waterville shows a classic landwash (area source) relation with riverflow: Fluxes increase as a function of the Waterville daily discharge, which is precisely what one expects of area sources, and the opposite of what one expects of point sources, which should be nearly independent of flow. After all, people don't produce orders of magnitude more waste because the weather is wet; but the lower Maumee (like most rivers) carries a hundredfold or a thousandfold more P, N, TDS, and SS in flood than it does in drought. Table 6-1 presents five full years of USGS data.

Toledo's wastes (even assuming the worst about them) are dwarfed by flood fluxes at Waterville. If the city's wastes were discharged without treatment of any kind, they would (on average) add about three tons of phosphorus and fifty tons of suspended solids to the river each day. Three tons is far short of 25 tons, and fifty tons is very far short of 100,000 tons. The traditional emphasis on violations of

TABLE 6-1. DAILY DISCHARGE AND FLUXES AT WATERVILLE: USGS DATA, 1965-1970

Date	Mean Discharge (cfs)	Total P (as PO_4) conc. (mg/l)	Total P (as PO_4) flux (tons/day)	Nitrate (as NO_3) conc. (mg/l)	Nitrate (as NO_3) flux (tons/day)	TDS @ 180°C conc. (mg/l)	TDS @ 180°C flux (tons/day)	SS conc. (mg/l)	SS flux (tons/day)
2 Oct 1965	410					424	469	17	18
24 Oct	14,800					324	12,947	170	6,800
8 Nov	860					394	915	17	39
30 Nov	1,880					496	2,518	22	112
1 Dec	1,940					494	2,588	20	105
29 Dec	13,500					262	9,550	110	4,010
2 Jan 1966	19,800					266	14,220	155	8,290
30 Jan	550					550	817	7	10
7 Feb	600					628	1,017	8	13
15 Feb	9,800					284	7,515	117	3,100
15 Mar	9,400					390	9,898	-	3,800
27 Mar	4,800					450	5,832	27	350
11 Apr	1,280					378	1,306	20	69
26 Apr	4,280					474	5,478	42	485
12 May	12,000					404	13,090	88	3,340
14 May	25,100					314	21,280	380	25,800
2 Jun	1,370					368	1,361	17	63
28 Jun	490					496	656	20	26
12 Jul	2,450					444	2,937	-	410
20 Jul	3,650					274	2,700	123	1,210
5 Aug	234					208	131	24	15
30 Aug	466					430	541	32	40
28 Sep	300					386	313	15	12
30 Sep	664					520	932	18	32
2 Oct	183			2.6	1.3	398	197	22	11
21 Oct	262			2.0	1.4	594	420	10	7
5 Nov	272			1.8	1.3	556	408	9	9
12 Nov	23,300			24	1,510	310	19,502	317	19,900
2 Dec	5,310			26	373	449	6,437	44	631
11 Dec	79,000			20	4,266	211	45,006	424	90,400
18 Jan 1967	840			20	45	566	1,284	4	9
31 Jan	7,960			28	602	430	9,242	41	881
16 Feb	15,900			15	644	418	17,945	62	2,660
20 Feb	10,700			19	549	291	8,407	170	4,910
9 Mar	6,700			23	416	516	9,334	16	289
14 Mar	28,400			27	2,070	280	21,470	194	14,900
1 Apr	22,400			23	1,391	274	16,571	321	19,400
28 Apr	4,180			20	226	392	4,424	97	1,090
5 May	2,280			15	92	432	2,659	47	289
11 May	22,700			22	1,348	264	16,181	332	20,300
4 Jun	1,310			9.5	34	406	3,723	18	64
12 Jun	1,270			5.9	20	464	1,591	34	117

Table 6-1 (cont'd)

Date	Mean Discharge (cfs)	Total P (as PO_4) conc. (mg/l)	Total P (as PO_4) flux (tons/day)	Nitrate (as NO_3) conc. (mg/l)	Nitrate (as NO_3) flux (tons/day)	TDS @ 180°C conc. (mg/l)	TDS @ 180°C flux (tons/day)	SS conc. (mg/l)	SS flux (tons/day)
12 Jul 1967	528			3.5	5.0	536	764	38	54
22 Jul	479			2.2	2.8	382	494	31	40
2 Aug	2,530			23	157	380	2,596	71	485
30 Aug	288			5.6	4.4	484	376	35	27
20 Sep	196			3.5	1.9	392	207	24	13
28 Sep	272	0.67	0.49	2.8	2.1	552	405	23	17
1 Oct	310			2.9	2.4	432	362	6	5
25 Oct	1,100			10	30	564	1,675	26	77
2 Nov	1,120			16	48	526	1,591	23	70
15 Nov	1,260			28	95	410	1,395	32	109
1 Dec	1,170			14	44	504	1,592	29	92
22 Dec	40,200			12	1,302	206	22,359	1,030	120,000
26 Jan 1968	3,500			9.4	89	570	5,386	47	444
31 Jan	52,000			11	1,544	174	24,430	407	57,100
1 Feb	51,600			5.4	752	190	26,471	278	38,700
27 Feb	1,200			20	65	442	1,432	14	45
15 Mar	1,160			9.2	29	482	1,510	16	50
29 Mar	18,900			28	1,429	284	14,493	157	8,010
6 Apr	25,700			14	971	266	18,458	605	42,000
25 Apr	2,470			6.6	44	414	2,761	47	313
15 May	2,600			8.3	58	388	2,724	28	197
28 May	43,500			31	3,641	224	26,309	839	93,500
1 Jun	21,600			38	2,216	304	17,729	208	12,100
24 Jun	1,400			3.4	13	374	1,414	16	60
1 Jul	9,270	0.62	15.5	41	1,026	330	8,260	143	3,580
22 Jul	2,070	0.90	5.0	13	73	430	2,403	39	218
1 Aug	1,750	1.1	5.2	5.7	27	362	1,710	46	217
21 Aug	3,600	1.7	16.5	4.6	45	232	2,255	670	1,350
7 Sep	230	0.72	0.5	2.2	1.4	250	155	22	18
30 Sep	752	1.5	3.0	1.4	2.8	410	832	10	20
7 Oct	500	1.3	1.8	5.1	6.9	438	591	10	14
21 Oct	340	0.85	0.8	1.2	1.1	398	365	7	6
4 Nov	340	1.2	1.1	5.1	4.7	444	408	10	9
25 Nov	2,200	1.4	8.3	28	166	466	2,768	28	166
16 Dec	1,300	1.0	3.5	22	77	440	1,544	32	112
30 Dec	38,500	0.72	74.8	9.0	936	246	25,572	550	57,200
6 Jan 1969	11,000	0.56	16.6	19	56	320	9,504	138	4,100
10 Jan	3,000	0.62	5.0	8.2	66	346	2,803	42	340
3 Feb	46,900	0.59	74.7	19	2,406	190	24,060	198	25,100
24 Feb	1,710	0.82	3.8	16	74	420	1,939	8	37
10 Mar	1,610	1.2	5.2	16	70	500	2,173	14	61
24 Mar	1,900	0.87	4.7	0.6	3.2	470	2,513	42	225
14 Apr	4,150	0.56	6.3	22	247	402	4,504	56	605

Table 6-1 (cont'd)

Date	Mean Discharge (cfs)	Total P (as PO_4) conc. (mg/1)	flux (tons/day)	Nitrate (as NO_3) conc. (mg/1)	flux (tons/day)	TDS @ 180°C conc. (mg/1)	flux (tons/day)	SS conc. (mg/1)	flux (tons/day)
21 Apr 1969	34,400	0.70	65.0	32	2,972	304	28,236	350	32,500
12 May	12,500	0.72	24.3	23	776	406	13,703	94	3,170
26 May	5,470	0.47	6.9	25	369	368	5,435	69	1,020
12 Jun	3,180	0.91	7.8	16	137	398	3,417	38	326
23 Jun	3,050	0.66	5.4	39	321	308	2,536	92	758
7 Jul	6,100	0.67	11.0	26	428	282	4,645	305	5,020
23 Jul	3,760	0.86	8.7	22	223	400	4,061	61	619
18 Aug	468	0.67	0.85	1.7	2.1	314	397	38	48
19 Aug	418	0.76	0.86	5.8	6.5	334	377	39	44
1 Sep	242	0.69	0.45	1.5	1.0	310	202	39	25
22 Sep	1,560	0.96	4.0	5.7	24	460	1,938	45	190
20 Oct	1,520	1.0	4.1	25	103	370	1,518	63	259
17 Nov	493	2.4	3.2	12	16	500	666	13	17
24 Nov	16,600	0.67	30.0	35	1,569	328	14,701	145	6,500
1 Dec	3,720	0.65	6.5	29	291	414	4,159	47	472
15 Dec	2,850	1.5	11.5	26	200	542	4,171	13	100
5 Jan 1970	750	1.5	3.0	18	36	522	1,057	6	12
23 Jan	500	2.2	3.0	19	26	608	821	4	5
1 Feb	22,000	1.4	83.2	21	1,247	312	18,533	220	13,100
2 Feb	25,000	1.6	108.0	23	1,553	246	16,605	330	22,300
12 Mar	6,760	0.58	10.6	25	456	352	6,425	53	967
23 Mar	7,360	0.86	17.1	22	437	448	8,903	61	1,210
15 Apr	13,100	0.72	25.5	26	920	364	12,875	238	8,420
27 Apr	18,400	0.56	27.8	25	1,242	294	14,606	212	10,500
11 May	2,050	0.64	3.5	20	111	416	2,303	58	321
18 May	18,200	0.59	29.0	29	1,425	282	13,857	410	20,100
10 Jun	2,490	0.89	6.0	38	255	418	2,810	64	430
24 Jun	1,170	0.77	2.4	46	145	446	1,409	98	310
20 Jul	6,560	0.93	16.5	25	443	408	7,226	134	2,370
27 Jul	1,840	0.77	3.8	26	129	298	1,480	143	710
4 Aug	2,420	0.93	6.1	22	144	398	2,600	103	673
25 Aug	269	0.84	0.61	4.6	3.3	314	228	22	16
7 Sep	208	1.1	0.62	4.4	2.5	334	188	28	16
30 Sep	811	1.6	3.5	6.2	13.6	438	959	36	79

concentration standards at drought flows gives a narrow, partial, rather distorted view of what the Maumee River looks like, and of what it does to Lake Erie. We urge that this traditional view be broadened to include consideration of fluxes at high flows, especially at flood peaks.

Since the dominant land use in the Maumee basin is intensive agriculture, it is of some interest to document how man has chemically altered the soils.[1] The USDA county agents we spoke to agree with the U.S. FWPCA's 1966 estimate[2] that over 90% of the land is in agricultural use. For the sake of conservative simplicity, let us assume that only 5,000 square miles are fertilized in an average year; this comes to 3.2 million acres.

According to the county agents we interviewed (whose statements were independently confirmed by the principal suppliers of agricultural chemicals in the basin: the Andersons and the Landmark-Farm Bureau Cooperative), the following quantities of fertilizers and pesticides are applied to each acre of cultivated land:

Nitrogen (as N): 100-200 lbs for corn and soybeans
200-300 lbs for tomatoes and specialty crops

Phosphorus (as P): 100-150 lbs for corn and soybeans
150-200 lbs for tomatoes and specialty crops

---

[1] The USDA, in cooperation with the Ohio Agricultural Experiment Station and the Ohio Dept. of Natural Resources, has published soil surveys for every county in the State. This continuing series has been prepared over the last several decades; copies may be obtained by writing to the USDA agent in each county, and they are often the only source, because some of the surveys have been out of print for many years. For example, the survey of Lucas County soils was published in 1934, and was last reissued in 1943.

[2] U.S. FEDERAL WATER POLLUTION CONTROL ADMINISTRATION (August 1966). Report on Water Pollution in the Maumee River Basin. Available from the U.S. EPA's Cleveland office. See page 4-8.

Potassium (as K): 100-150 lbs for corn and soybeans
150-200 lbs for tomatoes and specialty crops
Herbicides (Amiben, Atrazine, Lorox, etc.): 1-2 lbs
Insecticides (Furidan, Sevin, Lanate, etc.): 1-2 lbs
Fungicides (Maneb and related zinc compounds): 1-2 lbs

The chemical identity of the fertilizer varies somewhat, depending on market economics, but the most common form is a mixed blend of superphosphate, urea, ammonium and potassium salts.[1,2,3] Application rates vary with crop, soil structure, weather, pest severity, etc., and there is a strong seasonal effect. Fertilizers are plowed in all winter long, so long as the soil isn't too wet or frozen; peak application rates are in September (for winter wheat), November to December (for mild, dry, autumnal plowing of corn and soy fields), and March to April (for harsh or wet autumns and winters). Little fertilizer is applied from May to September, but pesticides are most heavily applied during the warm months.

If we multiply the lowest of the application rates by the 3.2 million acres that we have assumed to be under cultivation, we arrive at the following minimum dosages:

Nitrogen (as N): 320 million pounds a year
Phosphorus (as P): 320 million pounds a year
Potassium (as K): 320 million pounds a year

---

[1] OHIO STATE UNIVERSITY, COOPERATIVE EXTENSION SERVICE (undated). 1972-1973 Agronomy Guide. Bull. #472.

[2] U.S. DEPT. AGRICULTURE, CROP REPORTING BOARD (June 1971). Commercial Fertilizers. Statistical Bulletin #472.

[3] TVA, NATIONAL FERTILIZER DEVELOPMENT CENTER (January 1971). 1970 Fertilizer Summary Data. Bulletin Y-16 4M.

Herbicides: 3.2 million pounds a year
Insecticides: 3.2 million pounds a year
Fungicides: 3.2 million pounds a year

This conservative calculation comes to nearly 500,000 tons a year of primary plant nutrients and pesticides -- more than a third of all fertilizer used in Ohio.[1] During the 1973-74 planting season, application rates were said to have been higher than usual. If only one percent of these agricultural chemicals should be washed into the Maumee, the river will carry 5,000 tons of primary nutrients into Lake Erie this year. This amounts to a daily average nutrient flux of 30,000 lbs; because N and K compounds are much more soluble than P compounds, the 30,000 lbs/day should theoretically under-represent P, and should contain correspondingly higher proportions of N and K.

A comparison with Toledo's STP effluent may be informative. Based on the 1971 annual average concentrations and flow rates, the STP annually discharges 2,500 tons of nitrogen (as N) and 550 tons of phosphorus (as P). The crude simplifying assumptions of this argument are only meant to put the observable behavior of the Maumee's flowing loads into theoretical perspective. The point sources in the basin don't begin to account for the river's contents, insofar as we know them from the imperfect sampling procedures and analytical methods which have thus far been used to portray them. Everything we have learned about this river supports FWPCA's 1966 assertion that

> Even if all domestic and industrial wastes were removed from the Basin, there would still be significant water pollution problems present.... Trautman has described how particular agricultural practices have deteriorated the water quality

---

[1] U.S. DEPT. AGRICULTURE (June 1971). Op. cit., table 4.

> in the Maumee Basin. The only soil conservation practices instituted in the Basin seem to be drainage works. The idea appears to be to get the water off the land as quickly as possible, regardless of other considerations.. .. [B]esides having the greatest total amount of sediment load, the Maumee River also contains the finest sediment [scil., to be found in any of Ohio's rivers] .... The crops of some part of the Basin may have to be changed since beans and corn leave the land denuded in the wintertime. Strips of hay and grasses may be needed to help prevent erosion. Strip or contour farming may be needed in some almost flat areas to help prevent sheet erosion. *Op. cit.*, pp. 6-2 and 6-3, *passim*.

Lest agriculture be excessively blamed, it is prudent to recall that the Maumee estuary was turbid, filled with bars of sand, mud, and clay, and bordered by dank malarial swamps thousands of years before the basin was settled in the nineteenth century. These enormous deposits and fluxes must have come in large part from the upriver drainage area, even when it was covered with forests and swamps. The soft rock-flour soils of the basin are extremely susceptible to erosion. Though intensive agriculture has no doubt exacerbated these tendencies by loosening and denuding the soil, Mother Nature had arranged matters to ensure plenty of mass wasting (through a combination of wet climate and fine soil) long before the farmers gave her a hand. The Maumee does not drain a basin of resistant, crystalline rock in a semi-arid area. To envision a Maumee that is crystal-clear[1] and free of solids is to dream, to defy the geological and hydrological facts of life. But better soil conservation would do no harm.

Because the estuary is often quiet, and just below a long riffle that is usually free of bottom deposits, Toledo inherits (and stores both in its bedload and in the capacious estuarine channel) the wastes of the entire basin. In addition, it makes a hefty contribution to these accumulated wastes through its own municipal and industrial pollution. Because so much waste accumulates there, it is easy to pin a disproportionate share of the Maumee's problems on Toledo. The facts, however, admit of no such simplistic interpretation. In writing pollution-control permits for Toledo, we urge governmental officials to be mindful of the upriver heritage, of the large landwash effects, and of area sources; we counsel them to consider most carefully the complex estuarine hydraulics, which are totally unlike the hydrologic regime above the Perrysburg Bridge (RM 14); we hasten to remind them of the importance of adequate waste collection, and of the difference between a new treatment plant and a reliable one. Billions could be spent on a pollution-control program that will scarcely affect the Maumee's contents, or their effects on the troubled waters of Lake Erie.

---

[1] One of the most active conservation groups in Toledo is called Clearwater, Inc.; but the local baseball team is more realistically named "The Mud Hens".

7. RIVER SAMPLING

The hydraulic complexities of the estuary engender illimited combinations of conditions. We have studied just two of them. In our May survey the Waterville hydrograph was rapidly ascending from 1,600 to 20,000 cfs; we caught the river just as the Waterville discharge was passing through its historical average of 4,600 cfs. The estuary was extremely unstable during early May, but on 11 May the stage was fairly steady (it changed less than 0.65 ft), and on 12 May there was a powerful estuarine flush: The stage dropped nearly 2.5 ft in fifteen hours. We took samples for laboratory analysis during the rather quiet day of 11 May and during the strong flush of 12 May. Conditions in September were quite different. The Waterville hydrograph had for many weeks stayed well under 1,000 cfs; we studied the river as the hydrograph was falling from 736 to 220 cfs. The estuary was again unstable -- though it was less jittery than in May -- and there were long intervals of comparative calm. On the afternoon of 24 September, however, the estuary began a prolonged flush which lasted until noon on the 25th; during this interval the stage fell two feet. We took samples for laboratory analysis throughout the stagnant and flushing intervals. Figures 7-1 and 7-2 show the Waterville hydrographs during our May and September surveys; figures 7-3 through 7-7 are the estuarine stagegraphs from the May survey; figures 7-8 through 7-15 are the estuarine stagegraphs from the September survey; figures 7-16 and 7-17 are the stagegraphs at Buffalo on 24-25 September. Figures 7-14 through 7-17 show that as the lake fell at Toledo, it rose at Buffalo, and vice versa; the stagegraphs at Toledo and Buffalo during major lake changes are approximately inverted and concurrent, even though Toledo and Buffalo are at opposite ends of Lake Erie. The reciprocal relationship (which also obtained in May) confirms the general validity of the stagegraphs, though their fine structure may not be too accurate.

FIGURE 7-1.

WATERVILLE HYDROGRAPH
27 APRIL - 23 MAY 1974

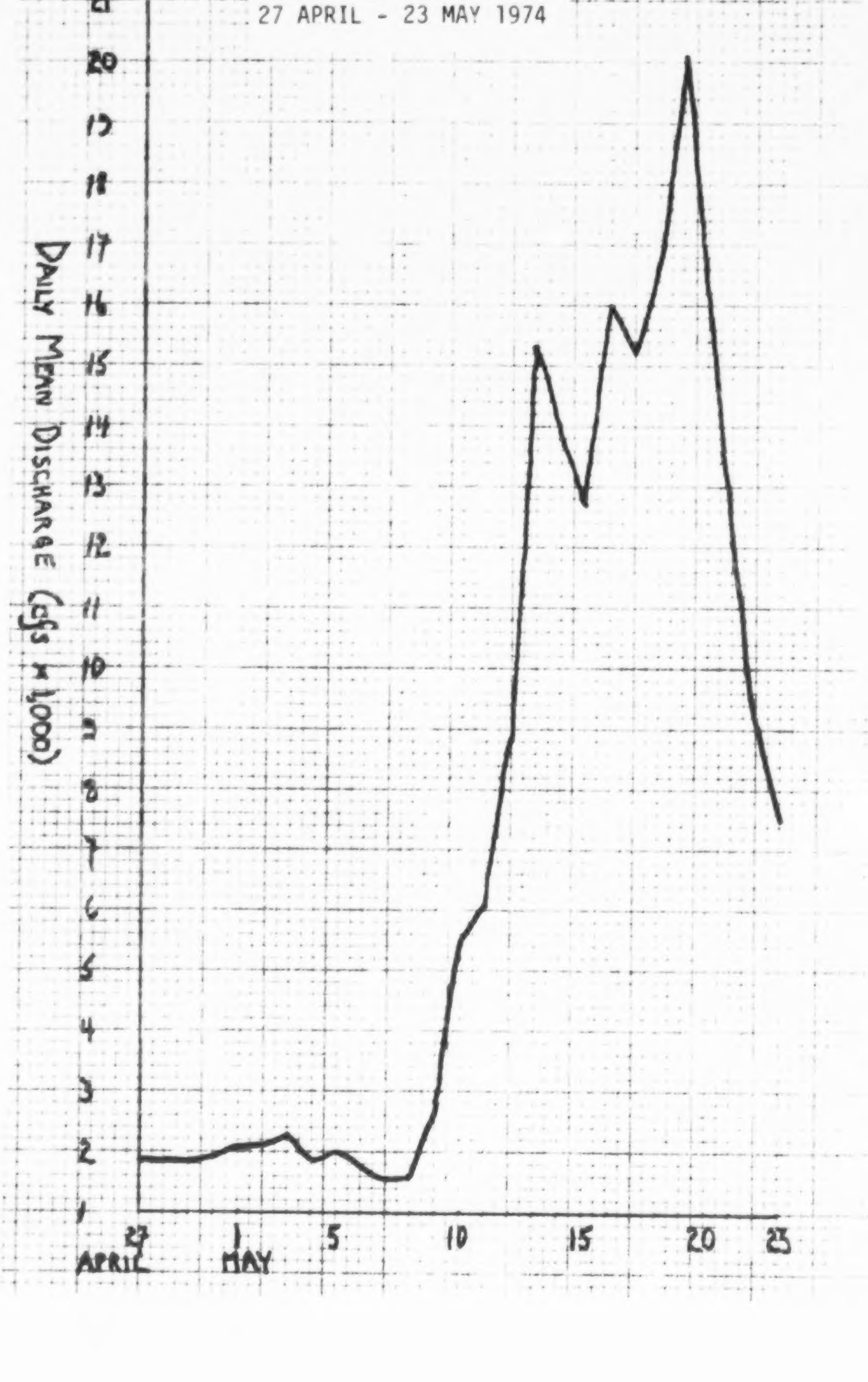


FIGURE 7-2.

WATERVILLE HYDROGRAPH
SEPTEMBER 1974

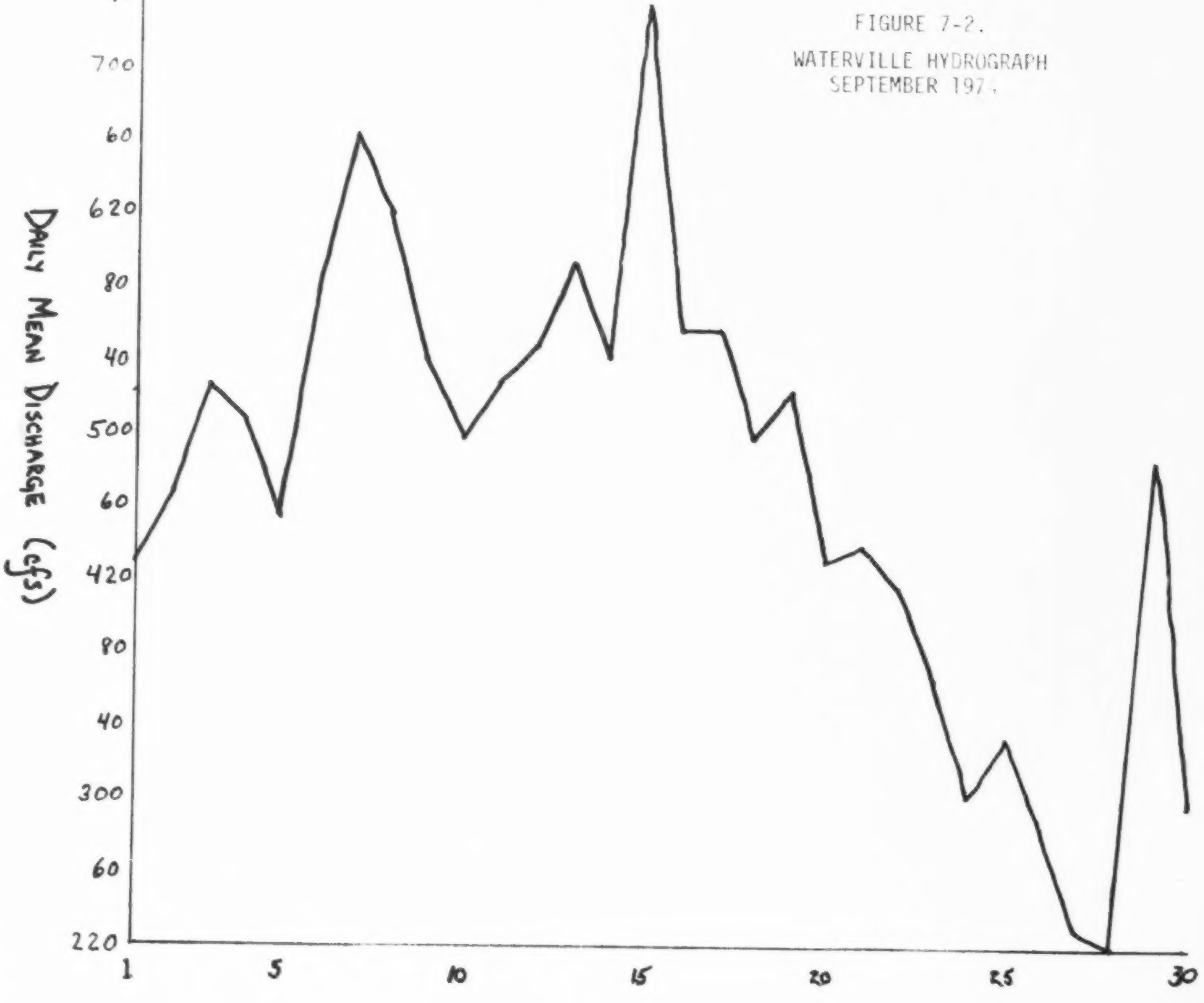


FIGURE 7-3.

STAGE HEIGHTS AT MOUTH OF MAUMEE
8 MAY 1974

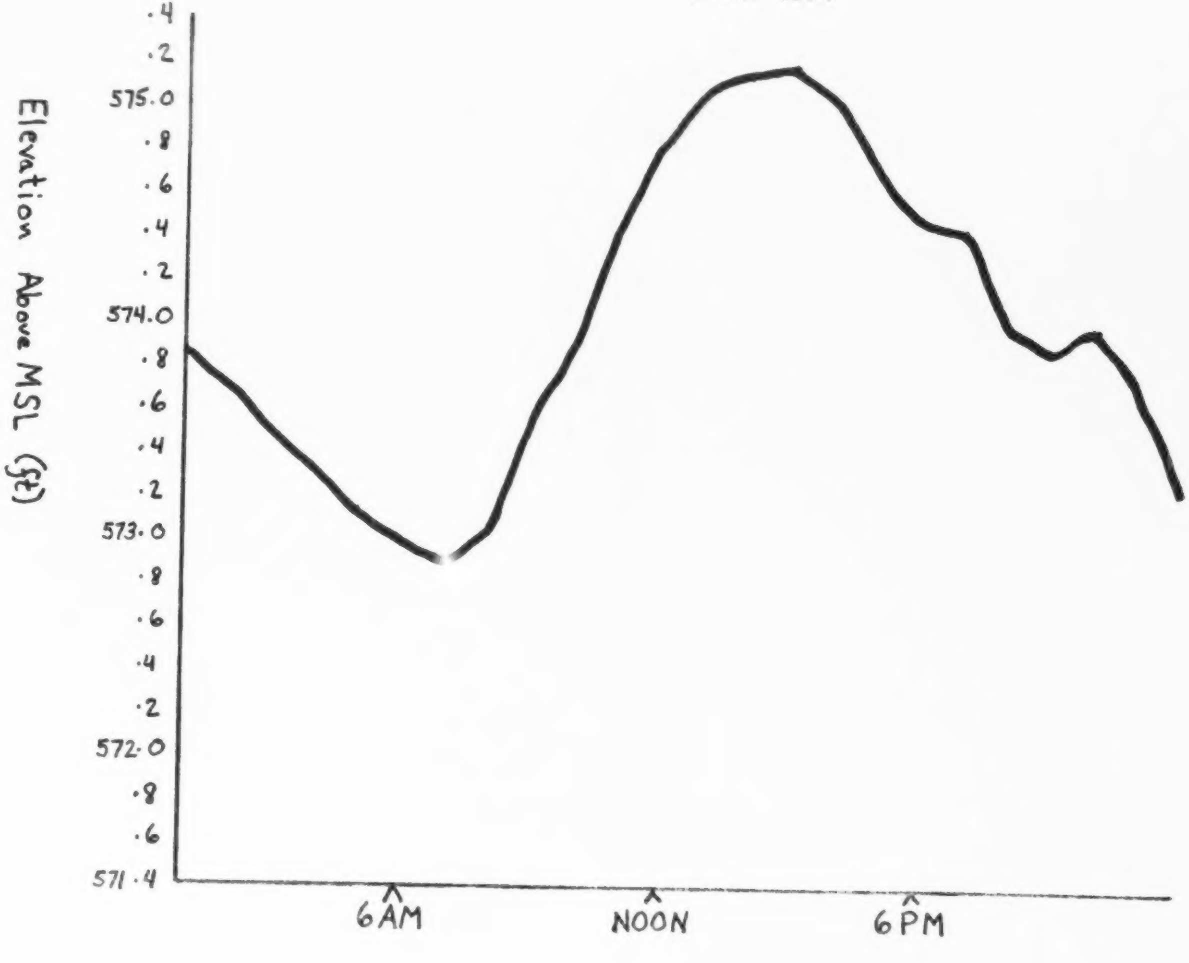


FIGURE 7-4.

STAGE HEIGHTS AT MOUTH OF MAUMEE
9 MAY 1974

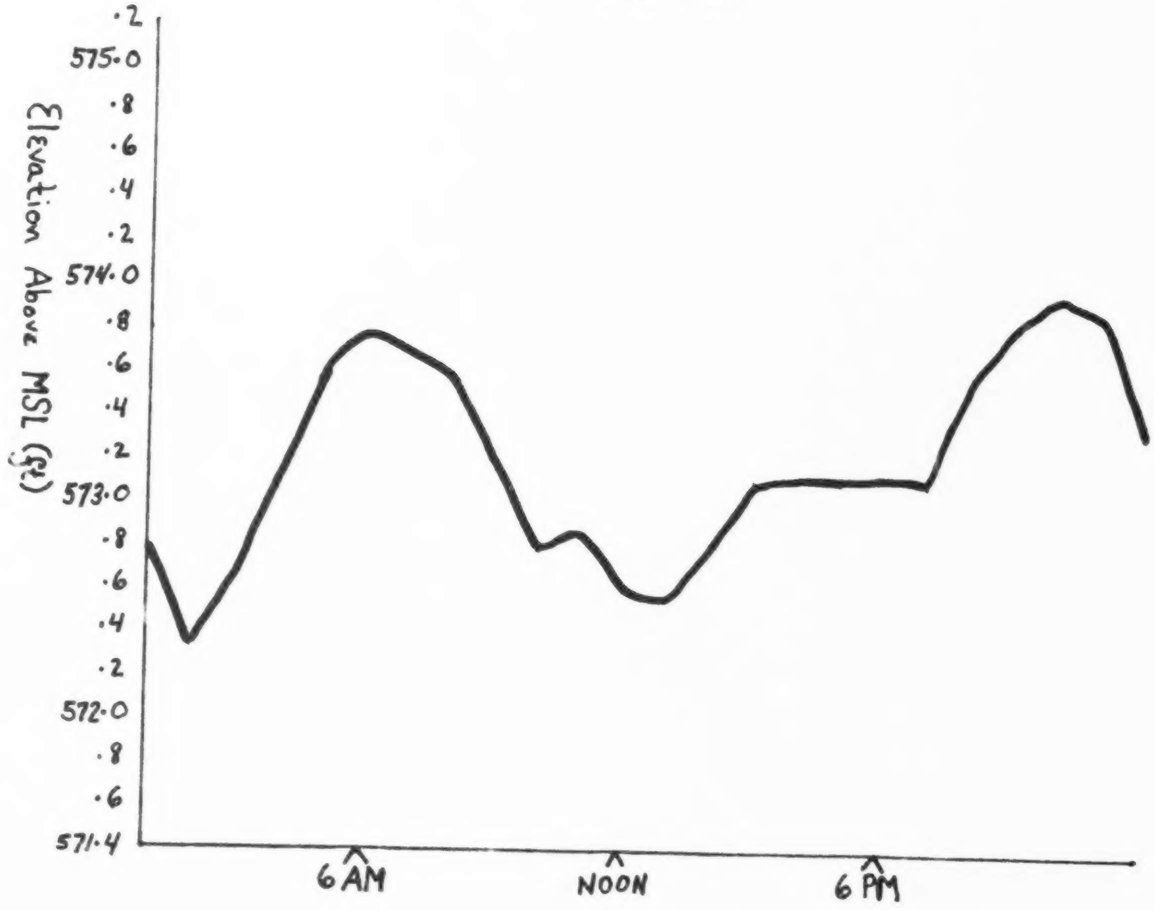


FIGURE 7-5.
STAGE HEIGHTS AT MOUTH OF MAUMEE
10 MAY 1974

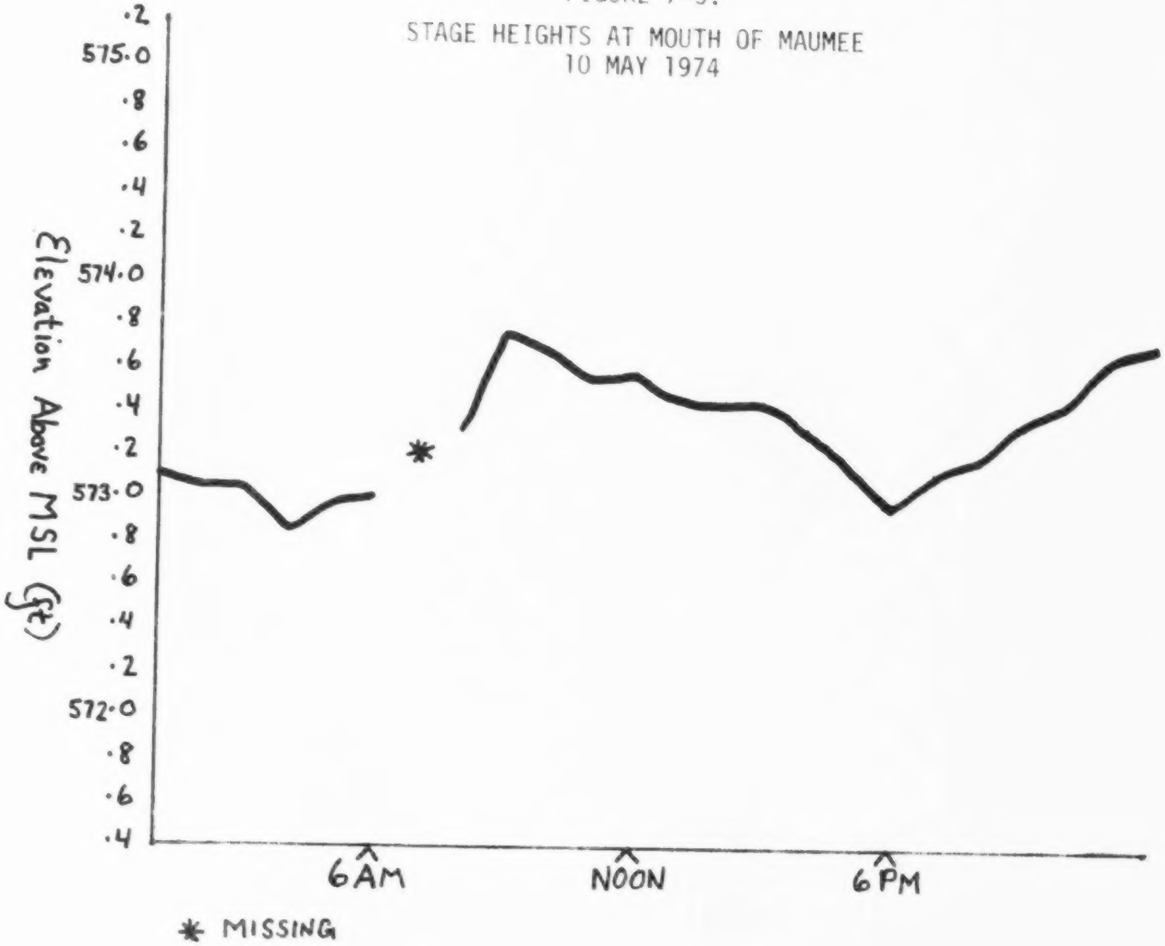


FIGURE 7-6.

STAGE HEIGHTS AT MOUTH OF MAUMEE
11 MAY 1974

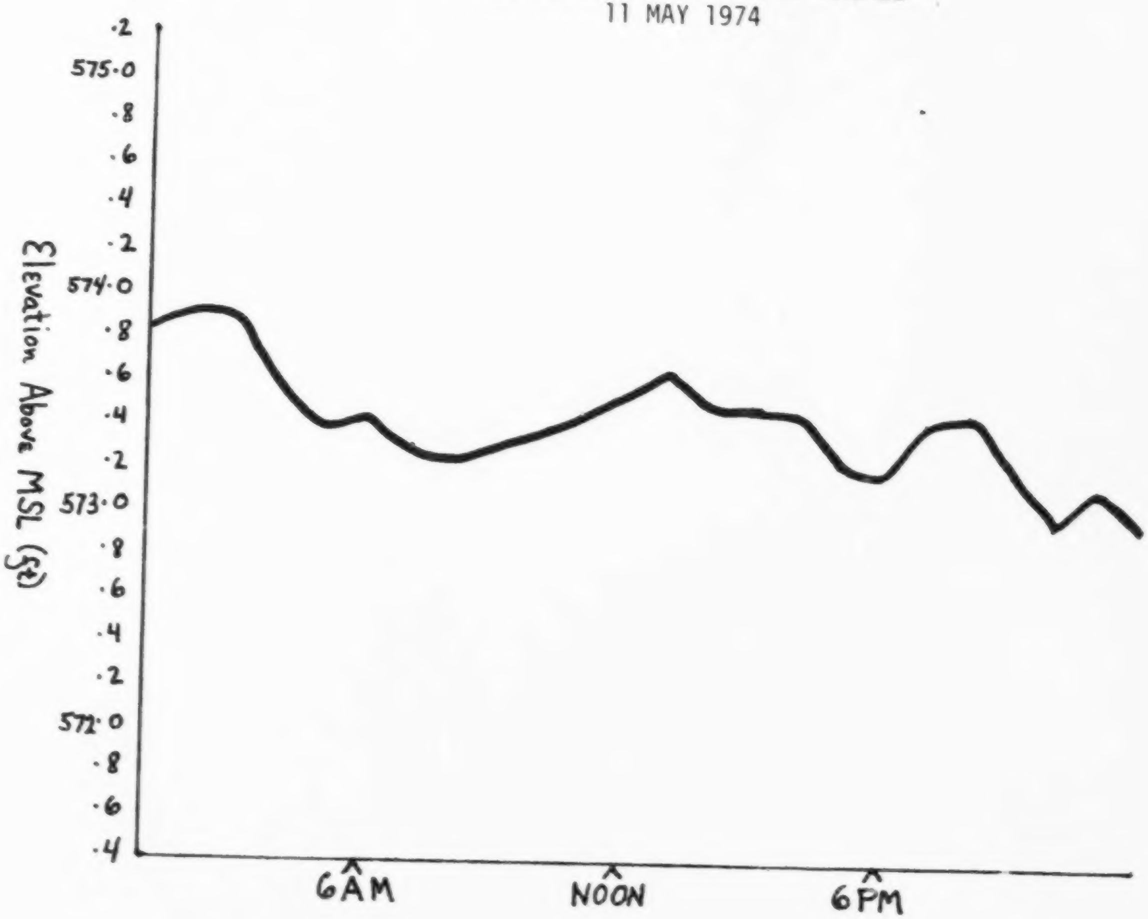


FIGURE 7-7.

STAGE HEIGHTS AT MOUTH OF MAUMEE
12 MAY 1974

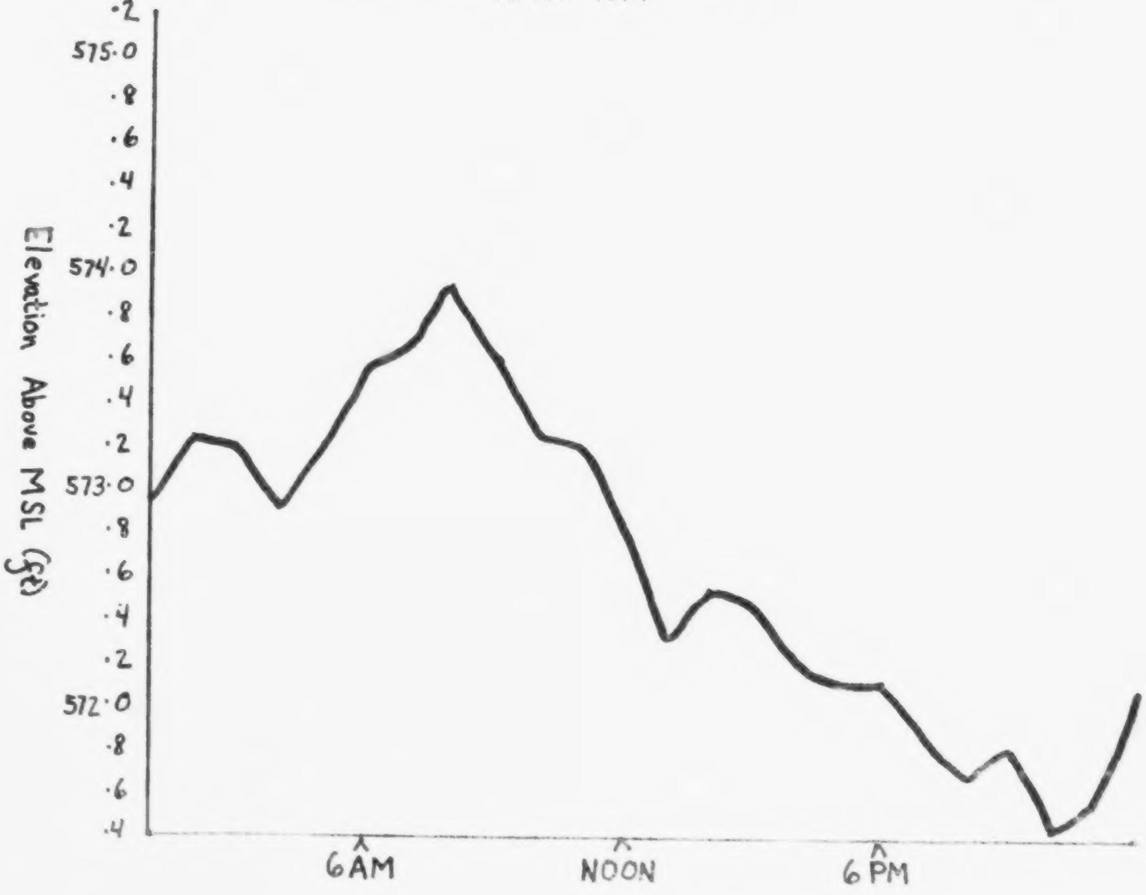


FIGURE 7-8.

STAGE HEIGHTS AT MOUTH OF MAUMEE
18 SEPT 1974

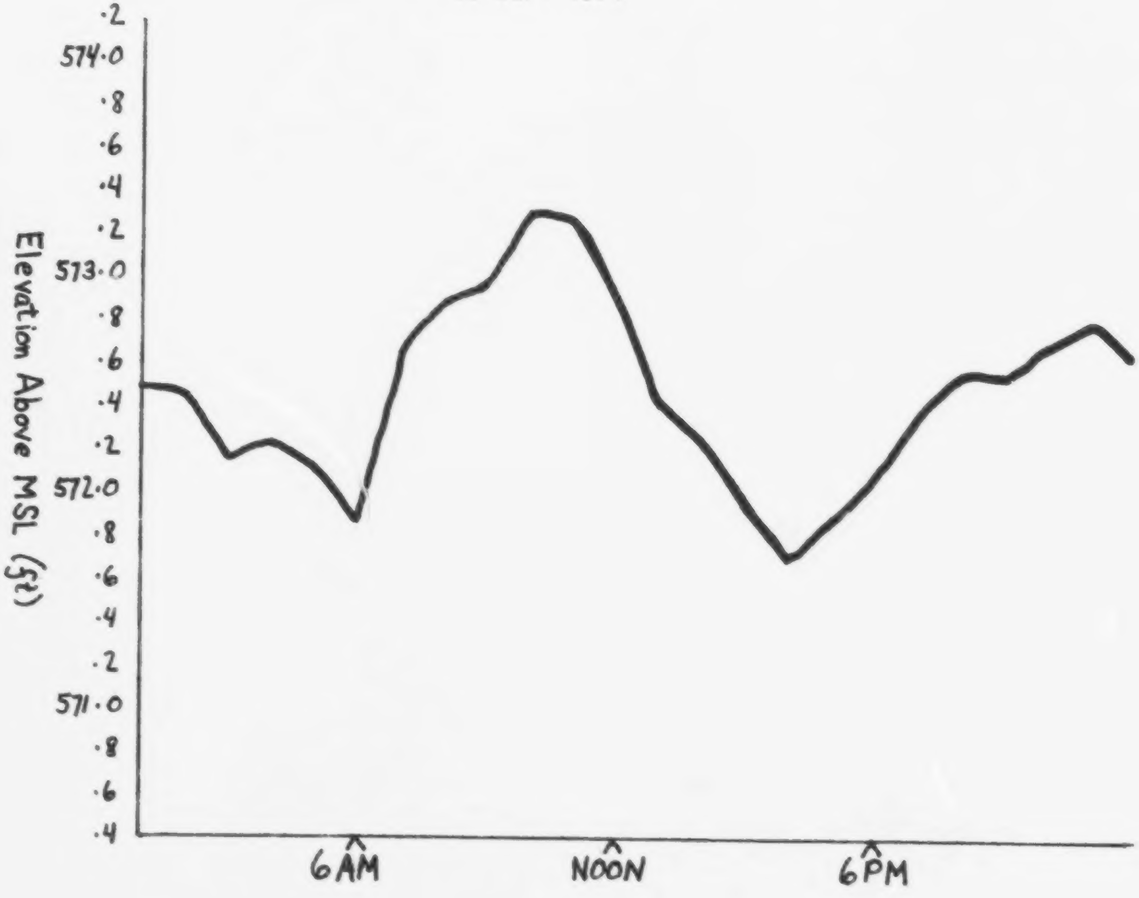


FIGURE 7-9.

STAGE HEIGHTS AT MOUTH OF MAUMEE
19 SEPT 1974

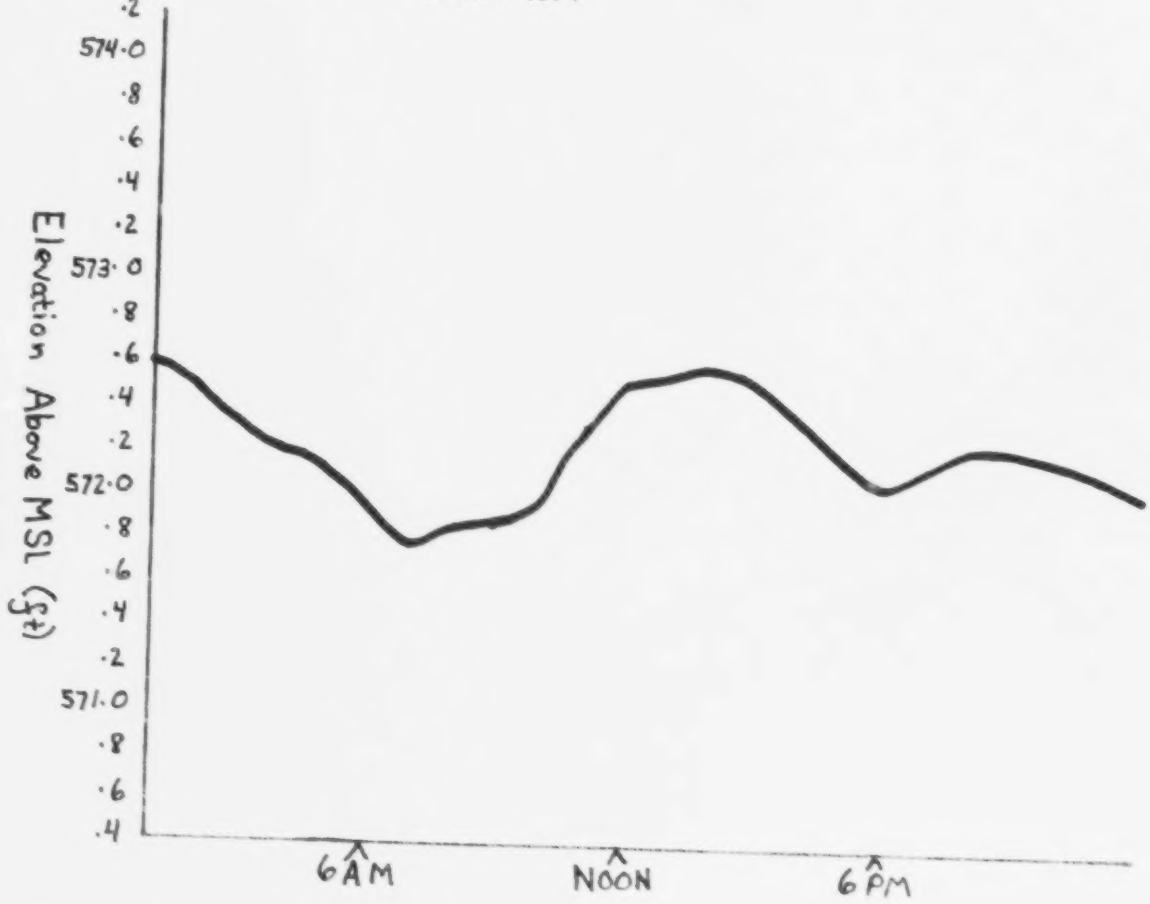


FIGURE 7-10.

STAGE HEIGHTS AT MOUTH OF MAUMEE
20 SEPT 1974

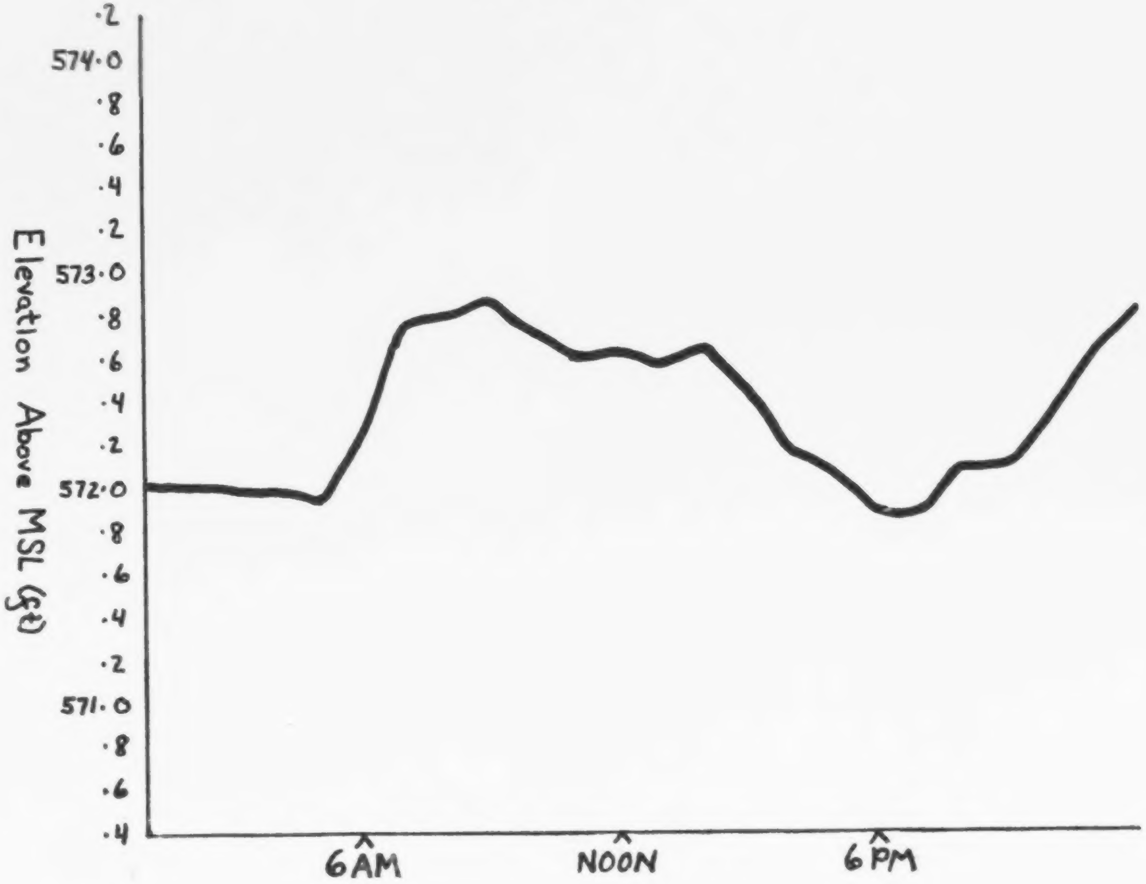


FIGURE 7-11.

STAGE HEIGHTS AT MOUTH OF MAUMEE
21 SEPT 1974

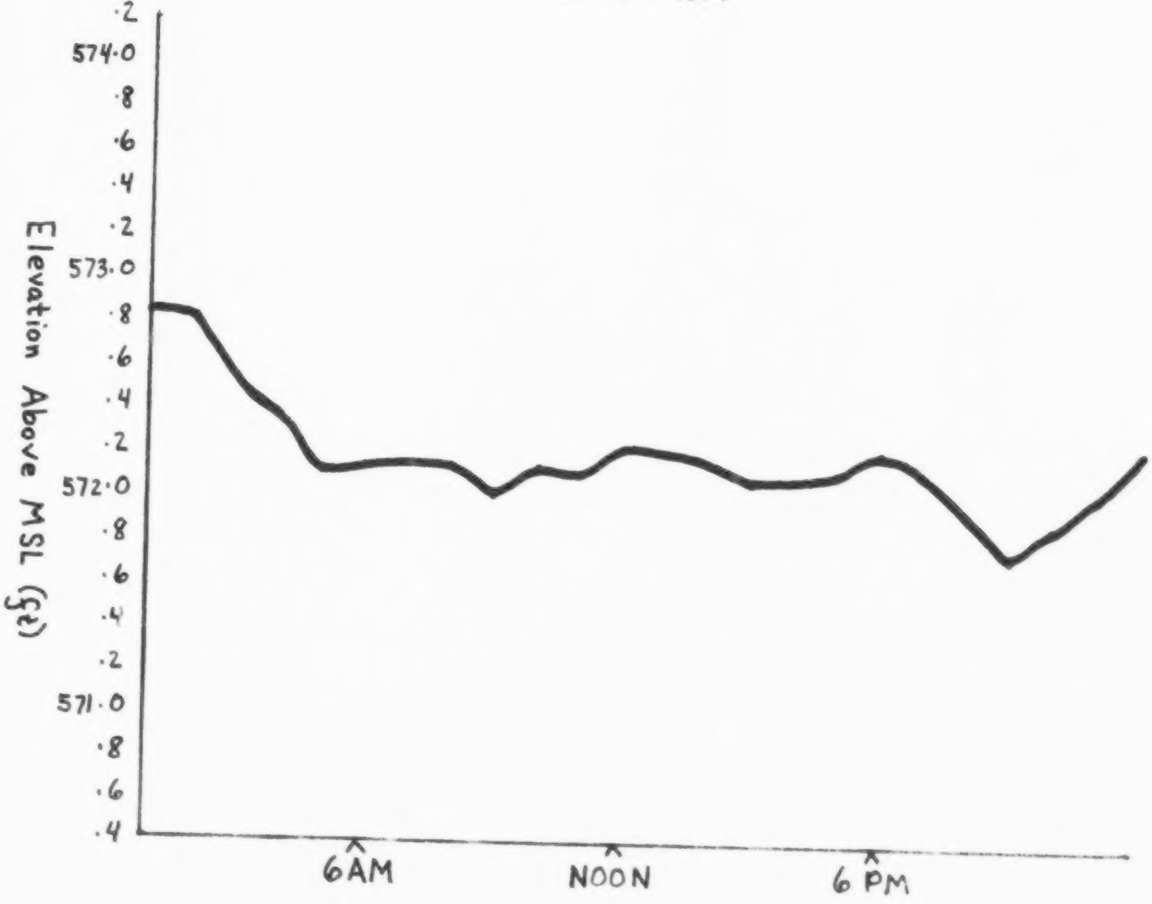


FIGURE 7-12.

STAGE HEIGHTS AT MOUTH OF MAUMEE
22 SEPT 1974

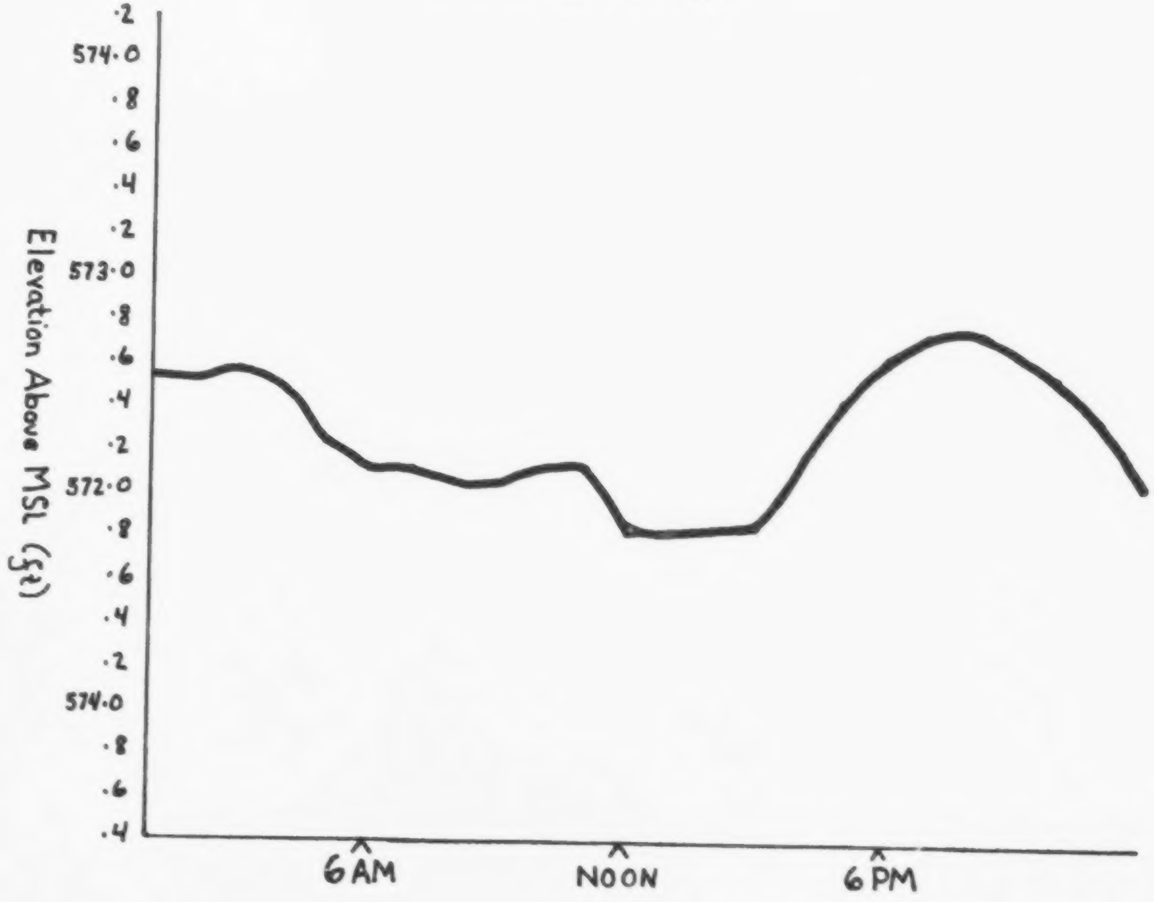


FIGURE 7-13.

STAGE HEIGHTS AT MOUTH OF MAUMEE
23 SEPT 1974

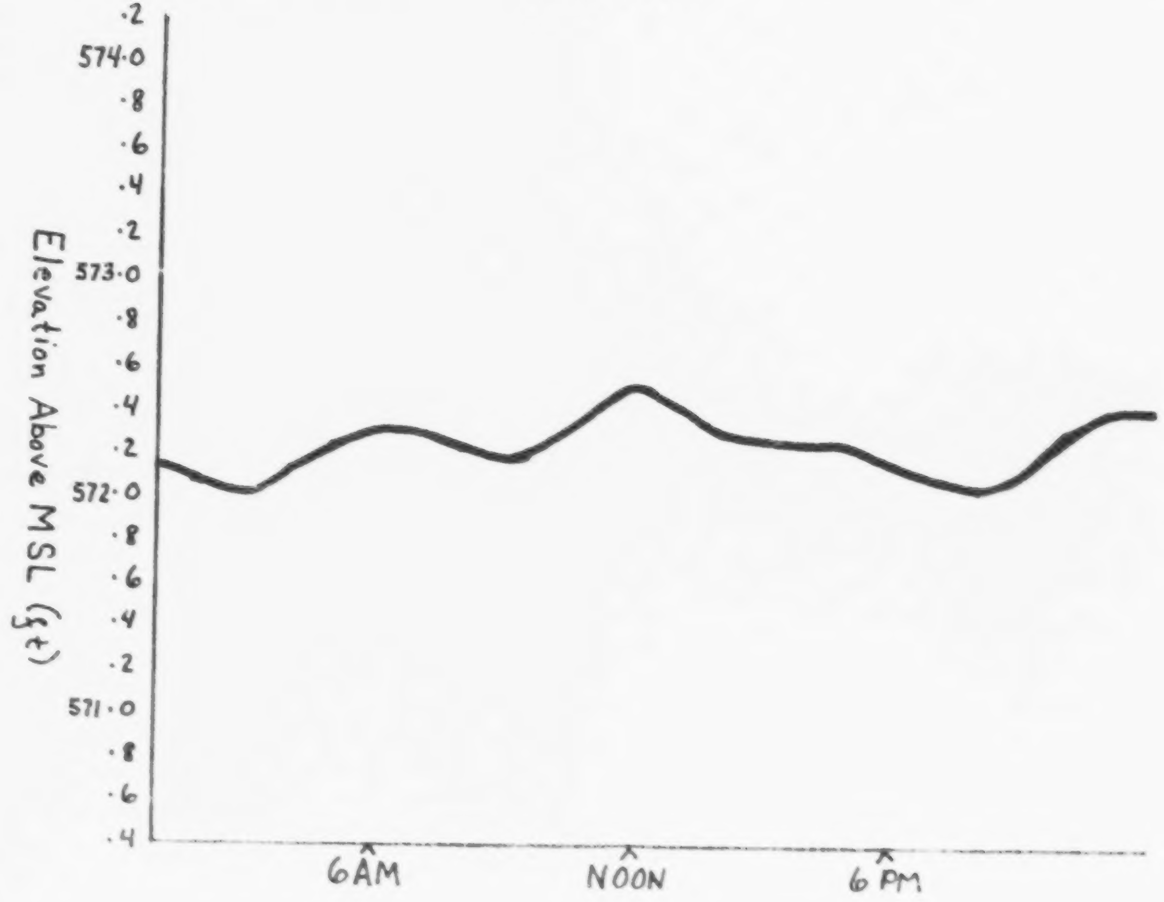


FIGURE 7-14

STAGE HEIGHTS AT MOUTH OF MAUMEE
24 SEPT 1974

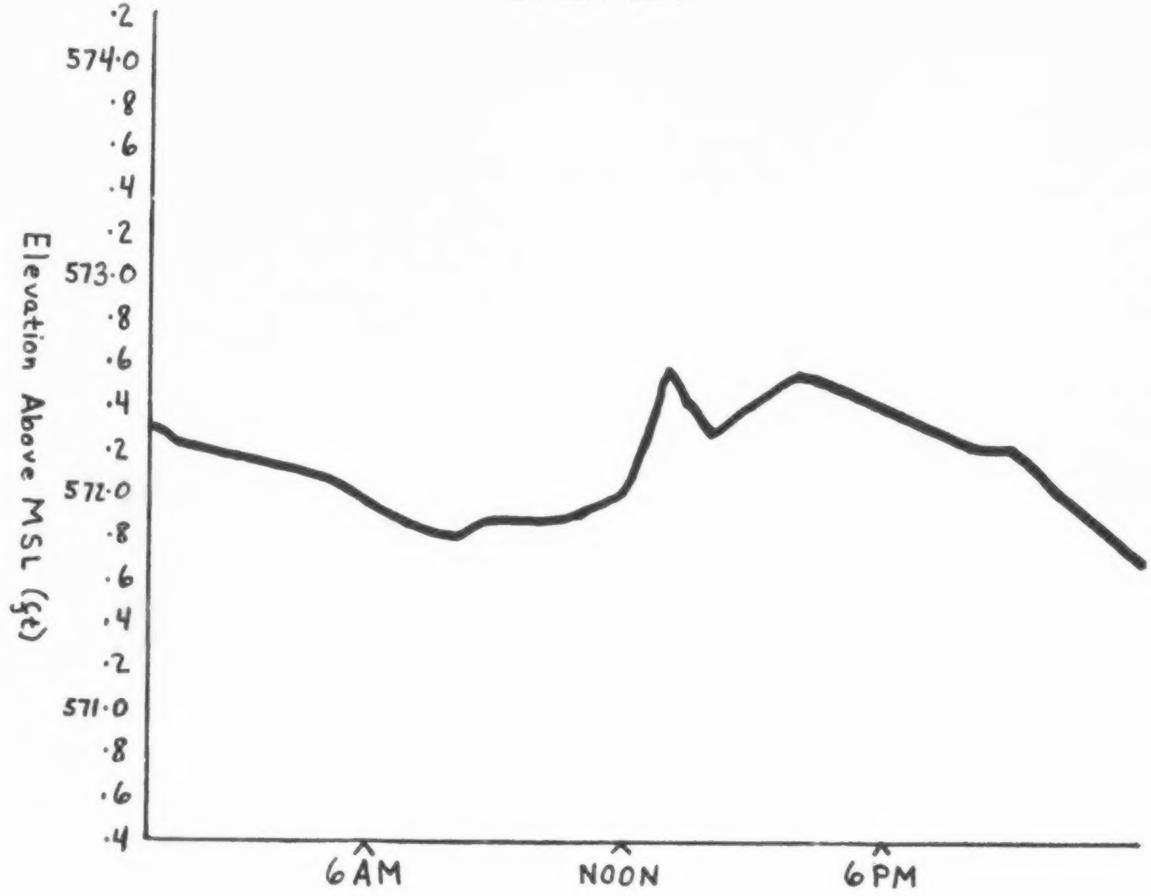


FIGURE 7-15.

STAGE HEIGHTS AT MOUTH OF MAUMEE
25 SEPT 1974

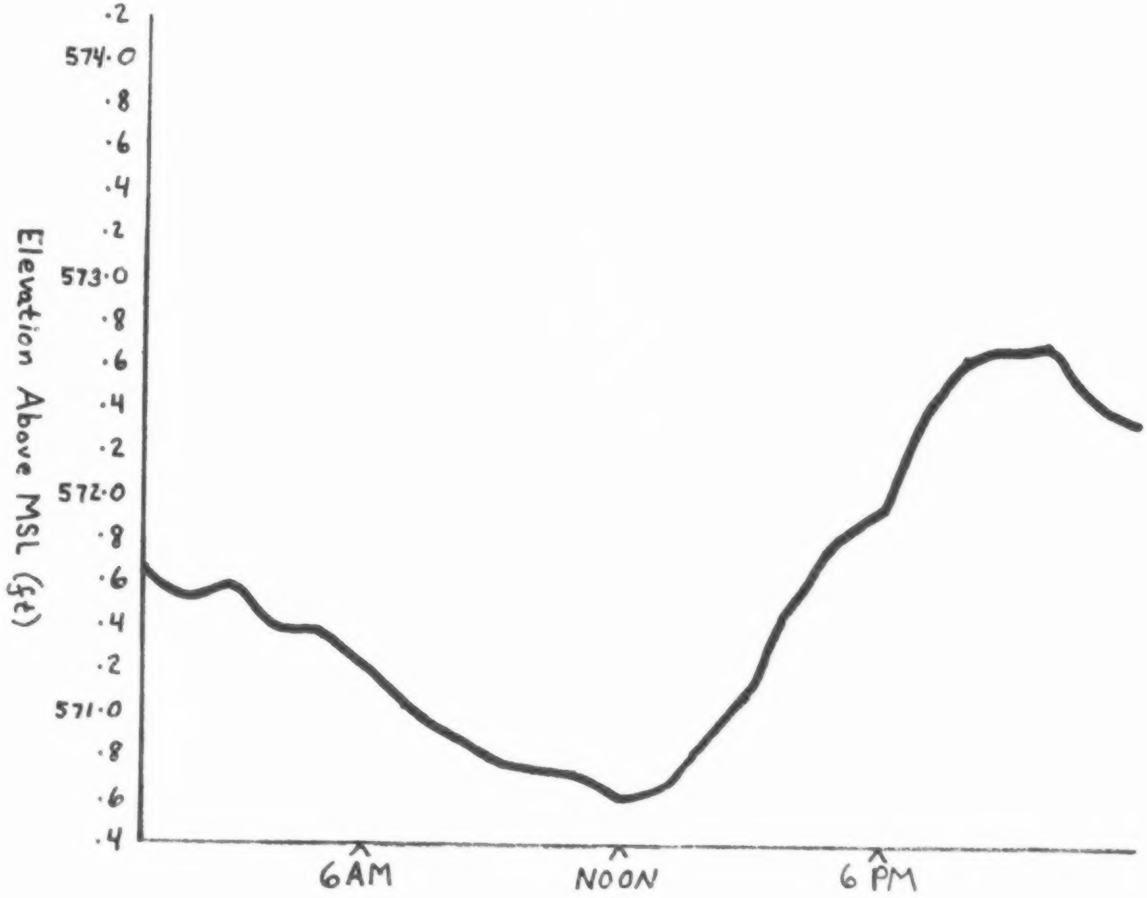


FIGURE 7-16.

STAGE HEIGHTS OF LAKE ERIE AT BUFFALO, N.Y.
24 SEPT 1974

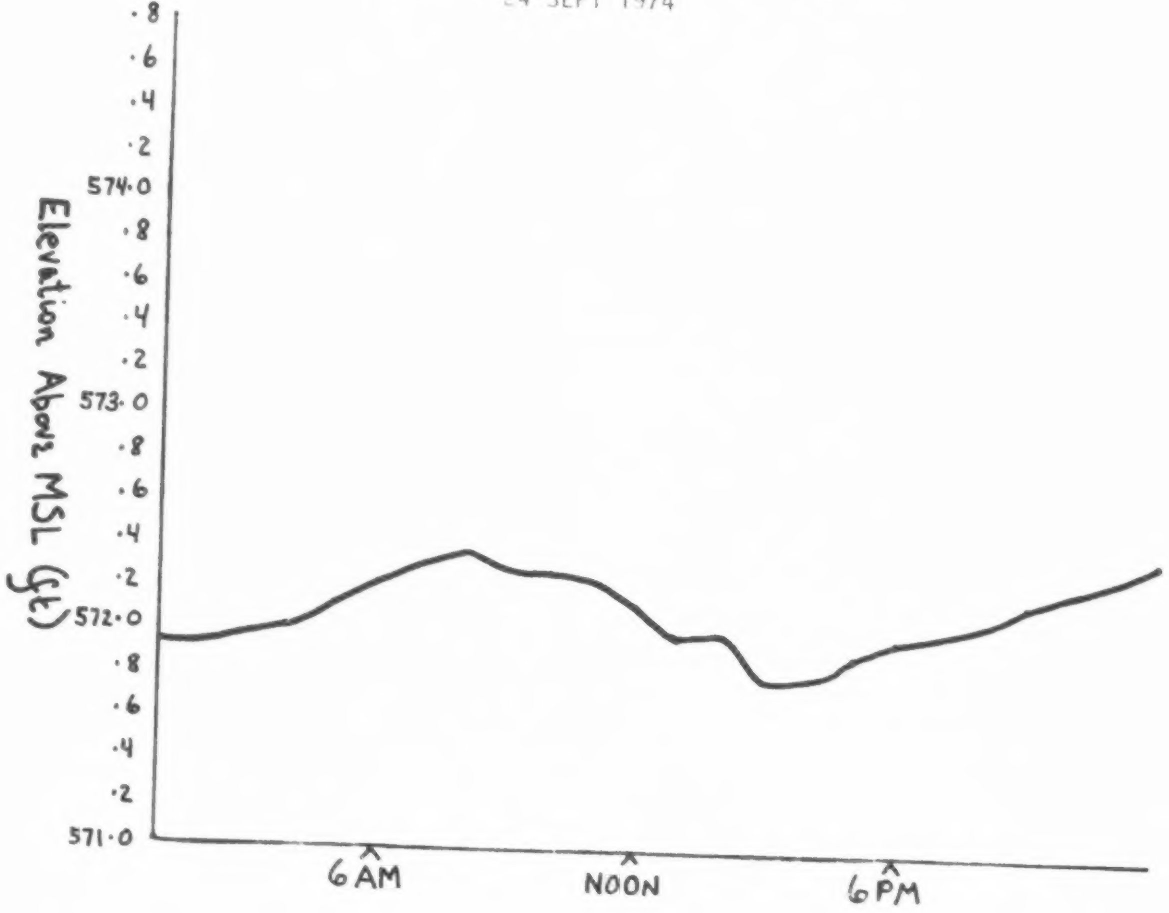
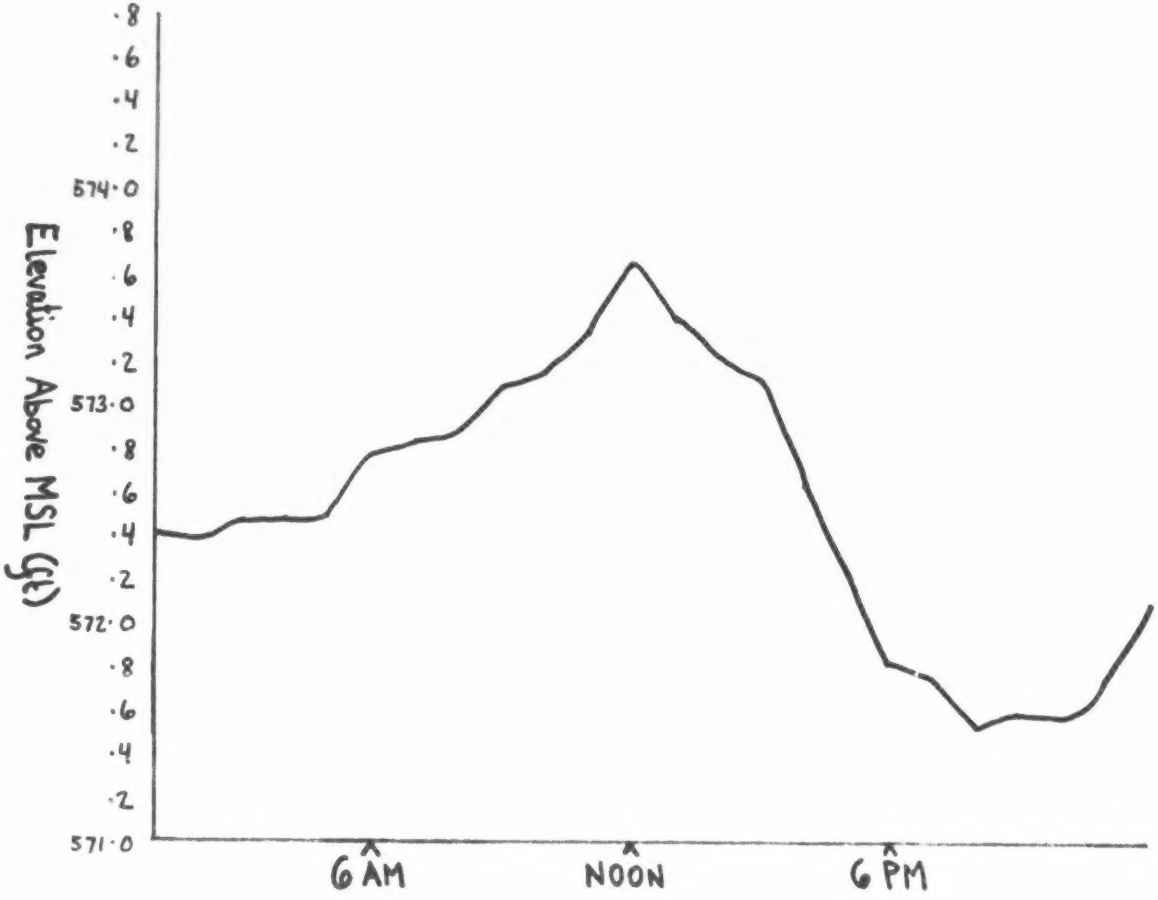


FIGURE 7-17.

STAGE HEIGHTS OF LAKE ERIE AT BUFFALO, N.Y.
25 SEPT 1974



The stagegraphs clearly illustrate stagnation, flushing, and reverse flow. As the stage rises, lake water is pushed into the estuary; as it falls, the river spills into the bay and the lake. The estuary is delicately poised: Each one-foot change in stage adjusts the estuarine volume by about 120 million cubic ft, and the adjustment is by no means simple. At each tiny quiver in stage, the proportions of lakewater and riverwater in the estuary are altered; the cumulative effect of many tiny stage changes may be as great as the effect of one extreme flush or backflow. Stage fluctuations set up powerful waves which traverse the estuary. These waves account for the characteristic sloshing of the lower river, and are the principal agent of estuarine mixing. To our knowledge, these waves have never been studied in the Maumee, even though the estuary's behavior can never be understood until they have been rigorously described and analyzed for several years. In consequence of our ignorance, we can say very little about flowing loads or material balances in the waters around Toledo. Furthermore, a great deal of material settles in the quiet estuarine waters and becomes part of the lodged sediment and the bedload; yet nothing is known about sedimentation or bedload dynamics in the lower Maumee, aside from records by the Corps of Engineers on the volume of dredge spoil they remove to maintain the navigation channel.

Until the estuarine, sedimentation, and bedload dynamics are at last known, no one can produce a defensible mass budget or wasteload allocation for the Toledo area. The fundamental data for load allocation cannot even be gathered until the estuary is at its hydrological worst, which is most likely when the stage is quite stable at a very low elevation (e.g., 568 ft), the estuary is filled with stagnant riverwater, and light winds prevent stage changes, flushing, or backflow. Lake levels have, however, been very high for the last several years, and there was plenty of lakewater in the estuary during both our surveys;

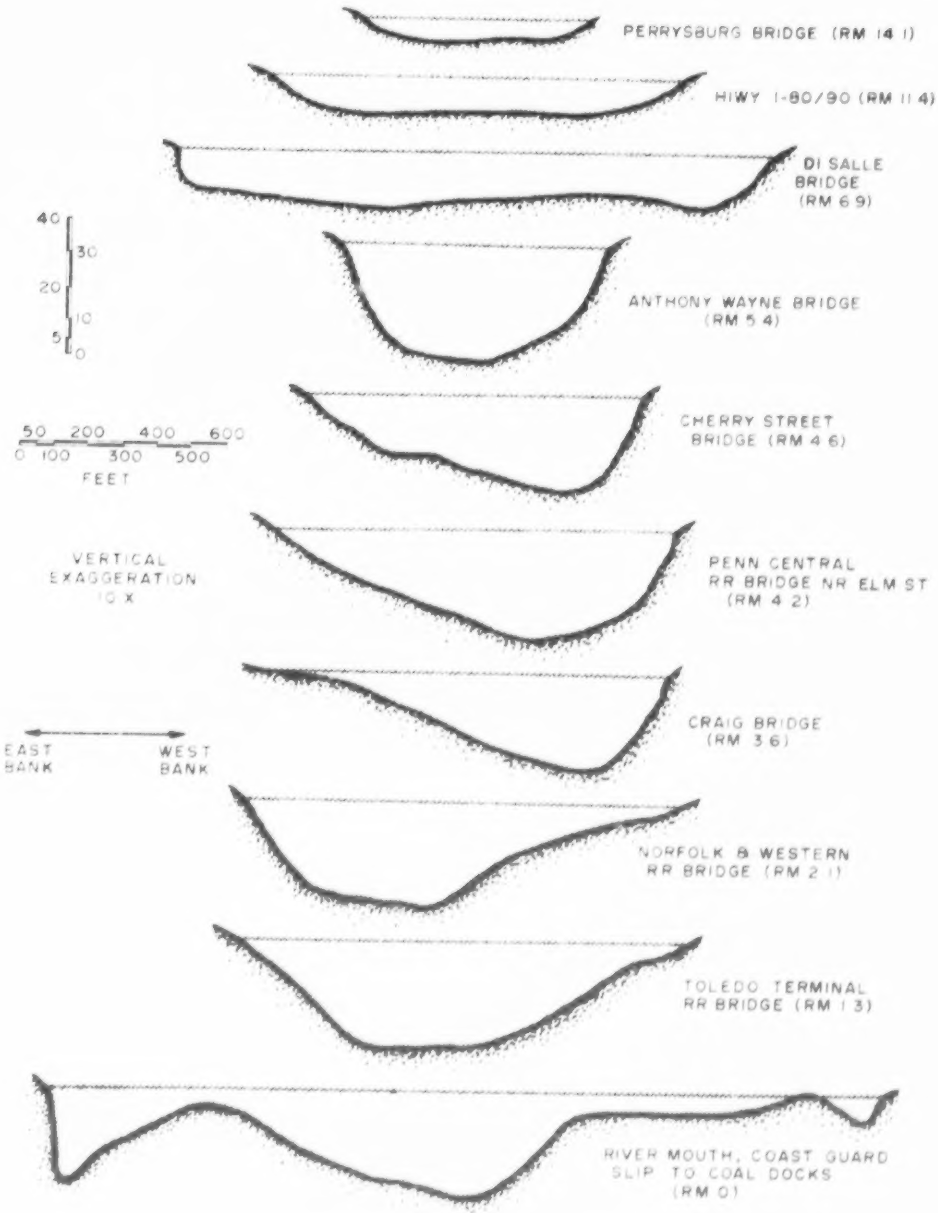
moreover, the stagegraphs could hardly be called flat and low on even the quietest of our days on the river. Consequently, we can do no more than lamely hope that our analyses may be useful to future students of the estuary when its dynamics are finally understood, and when the hydraulic and meteorologic conditions for extreme water-quality degradation at last beset Toledo. In how many estuaries, one wonders, have loads been allocated on the basis of dubious data on water quality, from samples taken when hydrological conditions were far from their worst, and in ignorance of hydraulics and sediment dynamics? One doubts that the Maumee and Toledo are unique.

In our limited experience, complex hydraulics and sediment dynamics are almost invariably slighted, despite the attendant intellectual perils. The principal features of the estuarine regime are stratification, backflow, and irregular times of passage; these three features must be incorporated into the sampling scheme. Horizontal and vertical stratification may be assessed with conductivity, DO, temperature, and pH probes. When the estuary is well mixed (i.e., unstratified), the probes will not show much difference from the top to the bottom of the water column, nor from bank to bank; when it is well stratified, one or more of the probes will register large differences with width or depth, and researchers must take care to analyze each stratum or cell separately. Appendix 1 gives a complete set of stratification data from our September survey. Figure 7-18 depicts cross-sections of the river at our principal transects.

Flow reversal and irregular times of passage can be followed with dye tracers, floats, or drogues. Dyes are in many ways more convenient than floats or drogues for studying passage times. However, dyes are susceptible to sorption, sedimentation, and scour (especially in waters as muddy and erratic as those of the Maumee estuary); hence, they have

FIGURE 7-18.

MAUMEE RIVER TRANSECTS


PERRYSBURG BRIDGE (RM 14.1)
HIWY I-80/90 (RM 11.4)
DI SALLE BRIDGE (RM 6.9)
40
30
20
10
5
0
ANTHONY WAYNE BRIDGE (RM 5.4)
50
200
400
600
0
100
300
500
FEET
CHERRY STREET BRIDGE (RM 4.6)
VERTICAL EXAGGERATION 10 X
PENN CENTRAL RR BRIDGE NR ELM ST (RM 4.2)
EAST BANK
WEST BANK
CRAIG BRIDGE (RM 3.6)
NORFOLK & WESTERN RR BRIDGE (RM 2.1)
TOLEDO TERMINAL RR BRIDGE (RM 1.3)
RIVER MOUTH, COAST GUARD SLIP TO COAL DOCKS (RM 0.1)

serious limitations as mass tracers, and are of very little help in documenting flow reversals because the dye will be folded back into itself whenever the lake rises: The virtues of dyes in studying diffusion are offset by their limitations in tracing eccentric transport. Drogues (or "floats", as they are often called in the older literature) vary in complexity from fresh oranges to sophisticated devices crammed with micro-miniaturized marvels of space-age technology. In principle, however, all drogues are alike: They are no more than current markers which float low enough in the water to escape being strongly influenced by the wind. Although they can be a terrible nuisance in shallow water, if they are carefully shepherded and freed from snags they can be used to follow both flow reversals and travel times.

We would be happy to report that a bag of oranges fulfilled every requirement, but we cannot: The estuarine currents were too often sluggish while the winds were strong, so our oranges usually spent little time in the water before being blown ashore. The chief outcome of these trials was fruit litter, for which we apologize, along handsome riverfront property near Ewing Island and Rossford. After experimenting with a variety of heavier improvised drogues (using lumber, bricks, ropes, bicycle flags, and stones), we hit upon a thoroughly satisfactory solution, whose simplicity and economy warm the heart. Our recipe calls for several dozen plastic milk jugs (one-gallon size, available from most dairies); various lengths of strong rope or clothesline; small pebbles, sand, or gravel; water (river water is handiest); several spraycans of day-glow paint (in assorted colors); and small flashlights (optional, but much recommended for night work). For each drogue, take one milk jug, put an inch or two of sand, gravel, or pebbles in it, fill it with water, then cap it. Now tie one end of a clothesline to its handle. Cut the line to any desired length (but keep it under 25' for the Maumee), and tie the other end to the handle of an empty milk jug.

Be certain to seal the empty jug, then lightly spray it with a color corresponding to the length of line that joins it to its waterlogged partner (e.g., red for a 5' line, green for 10', yellow for 20'). For ease in tracking positions at night, a small flashlight may be placed in the otherwise empty top jug. Total preparation time is less than five minutes; cost of materials is a few cents. The colorful top jug clearly marks the position of its submerged travelling companion. To avoid any possible confusion between a fully solid-state drogue (such as might be used in a weighty systems analysis study) and this trifling improvisation, we shall simply call our jugs "jugs".[1] One item of ancillary equipment is much recommended: a buoy hook (which may be improvised from a broomstick and a strong metal hook) for rounding up errant jugs that have strayed from the herd and gotten snagged in shallow water.

In addition to probes and jugs, we used a Columbia AquaProbe (September only) and a measuring line (a mushroom anchor on a heavy steel chain) for sounding depths, a Davis rangefinder, Kemmerer and Van Dorn samplers, acid-washed Nalgene bottles for sample storage (thoroughly rinsed with the river water to be analyzed just before being filled) ice chests, and the customary glassware and reagents for Winkler titrations (to verify that the DO probe was in calibration). The 1971 edition of the U.S. Lake Survey's navigation charts was indispensable.[2]

The frequent flow reversals deserve some comment. They have little relation to the Waterville discharge or to the local wind: We frequently saw the jugs travelling upriver against a gusty southwest wind in both

---

[1] Our thanks to William A. Tank, Jr., who calls things as he sees them, for suggesting this compact nomenclature.

[2] U.S. LAKE SURVEY (1971). Chart No. 370, West End of Lake Erie, Recreational Craft Series. The Survey, Detroit.

May and September. For example, the strongest reversal we saw was just after dawn on 12 May. The wind was gusting out of the south and west, and rain (varying from a fine drizzle to torrential downpour) was falling. The Waterville gage had read 6060 cfs on 11 May, and rose to 8840 on 12 May. Yet the backflow at Cherry Street (RM 4.6) was so strong we could barely hold on to a 15-lb mushroom anchor suspended from a heavy chain. Figure 7-7 shows why the backflow was so strong: The stage rose nearly a foot between 04:00 and 08:00. Jugs, on 2' to 12' lines, released at 07:47 at Cherry Street, had been shoved back to Promenade Park by 08:30, when the current changed again; by 09:25 they had returned to Cherry Street Bridge.

We saw no fixed relationship between stratification and flow reversals, and (during our two surveys) stratification was rare and slight except at the Craig Bridge (RM 3.6, where the river is thermally stratified by the Acme plant's cooling-water discharge) and at the mouth. Indeed, during 3-12 May we never saw more than a slight sign of stratification. Whether this behavior is typical we cannot say. On 10 May, the flow at Cherry Street Bridge (as measured by USGS) fell from 1 fps at 12:30 to zero at 13:20; at 14:45 the flow was zero at the Craig Bridge, with a barely perceptible suggestion of backflow just above the bottom. Even during these intervals of stagnation and backflow, however, there was no evidence of stratification. (See figure 7-7, which shows that the estuary was nearly stagnant during the early afternoon.) On 22 September, between 16:15 and 16:30, the stage was rising (see figure 7-12) at about 0.1 ft per hour; the flow reversal was confirmed by USGS spot measurements at the mouth (minus 0.4 fps) and by the jugs' moving upriver against the wind from the Anthony Wayne Bridge (RM 5.4) at approximately 0.6 fps. Although the backflow had begun over an hour before, the mouth was unstratified with respect to conductivity, nearly unstratified with respect to temperature, and only slightly stratified with respect to DO (less than 1.2 mg/l difference between the top and the bottom of the water column at mid-mouth; see Appendix 1). On 23 September at 15:11, when the stage was holding steady (see figure 7-13), the mouth was strongly stratified in every respect; and on 24 September at 11:30-11:45, the mouth was again strongly stratified in every respect, though the stage was slowly rising (see figure 7-14). Such phenomena cannot be explained by any mathematical model we know of, and, though our ignorance is vast, we suggest that the estuary be much more thoroughly studied before being subjected to computerized flights of deductive fancy.

For easier reporting, we have adopted the following convention. Although the Maumee meanders, and is S-shaped between DiSalle Bridge (RM 6.9) and Cherry Street Bridge (RM 4.6), we shall hereinafter call everything on the Toledo STP-Swan Creek-Fort Miami side of the river "west"; everything on the Oregon-Acme powerplant-Perrysburg side is "east". Except at the mouth, all samples were taken at bridges, from the upriver side, regardless of flow direction, unless specifically noted otherwise. Perrysburg samples were taken from the bridge, though stratification analysis was also done from a boat there. All other samples were taken from a boat. Bridge piers, consecutively numbered from "east" to "west", are the reference points whenever possible; in other cases sampling points are identified by navigation buoys or by distance from shore. See Appendix 1 for details.

In May we used three transects for a total of ten sampling stations, as follows:

Perrysburg Bridge (Ft Meigs Memorial Bridge, RM 14.1)

1. East - between piers #2 and #3
2. Mid - between piers #4 and #5
3. West - between piers #6 and #7

Cherry Street Bridge (RM 4.6)

4. East - pier #2

5. Mid - between piers #5 and #6, which support the liftspan
6. West - pier #7

Mouth (RM 0, a straight line from the coal docks to the Coast Guard Slip, passing between buoys #49 and #50)

7. East - six feet from tip of coal-dock jetty (first jetty east of Duck Creek mouth)
8. Mideast - black buoy #49, at eastern edge of navigation channel
9. Midwest - red buoy #50, at western edge of navigation channel
10. West - white buoy (unnumbered), 150 feet east of Coast Guard slip.

In September we used eight transects for a total of eleven sampling stations, as follows:

1. Perrysburg Bridge - between piers #3 and #4
2. Highway I-80/90 Bridge (RM 11.4) - pier #4

DiSalle Bridge (Highway I-75 Bridge, RM 6.9)

3. Middle - pier #5
4. East - pier #2
5. Anthony Wayne Bridge (RM 5.4) - midway between red bridge lights marking the navigation channel
6. Cherry Street Bridge (RM 4.6) - between piers #5 and #6, which support the liftspan

Craig Bridge (Highway I-280 Bridge, RM 3.6)

7. Mid - pier #3
8. West - pier #5
9. Toledo Terminal Railroad Bridge (RM 1.3) - pier #3

Mouth (RM 0, at buoys #49 and #50)

10. Mid - halfway between buoys #49 and #50
11. West - white buoy (unnumbered), 150 feet east of Coast Guard slip.

Each transect was checked with probes for signs of stratification before samples were collected for laboratory analysis. In May at least three samples were taken at each transect, although the probes showed no stratification (the absence of significant stratification was confirmed by TDS analyses and by most other analyses everywhere except at the mouth on 12 May, when violent waves made it impossible to read the meters). In September only one sample was taken at each transect unless there were clear signs of stratification; the estuary was stratified in the vicinity of the jugs on three occasions:

- Strong vertical stratification with respect to conductivity, and relatively mild horizontal stratification with respect to DO, at DiSalle Bridge on 23 September, 08:45. The vertical stratification was probably due to an old aquifer's being torn open by sand-dredgers, which were active in the vicinity; the abnormally low conductivity could not be found anywhere else in the river that morning.

- Horizontal stratification with respect to DO, and mild vertical stratification with respect to conductivity, at Craig Bridge on 25 September, 02:40.

- Horizontal stratification in every respect, and vertical stratification with respect to conductivity, at the mouth on 25 September, 09:25.

Tables 7-1 through 7-6 summarize the results of our May survey. The estuarine flush on 12 May is evident in the TDS values, which rose 10% at Cherry Street and the mouth between 11 and 12 May: Saltier water from upriver invaded the lower estuary and decreased the proportion of cleaner lakewater there. Despite the gushing sewer overflows

TABLE 7-1. PERRYSBURG BRIDGE, 10 MAY 1974, 20:40-21:00

	Concentration (mg/l)		
Parameter	East @ 3'	Mid @ 3'	West @ 3'
SS		43	44
TDS	488	474	
Total C	46.5	48.1	
Organic C	12.5	13.2	
Inorganic C	34.0	34.9	
Total N		3.10	
Kjeldahl N	0.68	0.68	
Ammoniacal N		0.27	
NO_3 N		2.10	2.22
NO_2 N		0.046	
Total P		0.19	0.20
Dissolved P	0.14	0.15	
COD		35.1	39.2
14°-BOD_1		0.9	
14°-BOD_5		3.1	
14°-BOD_{10}		5.0	
14°-BOD_{20}		7.4	
14°-BOD_{30}		9.0	
20°-BOD_1		0.8	
20°-BOD_5		5.7	
20°-BOD_{10}		11.1	
20°-BOD_{20}		21.4	
20°-BOD_{30}		21.4	

TABLE 7-2. PERRYSBURG BRIDGE, 11 MAY 1974, 18:15-19:00

	Concentration (mg/l)		
	East @ 3'	Mid @ 3'	West @ 3'
Parameter			
SS		59	59
TDS	437	445	
Total C	52.9	52.0	
Organic C	16.9	16.0	
Inorganic C	36.0	36.0	
Total N		2.96	
Kjeldahl N	0.43	0.80	
Ammoniacal N		0.27	
NO_3 N		1.86	2.52
NO_2 N		0.028	
Total P		0.20	0.20
Dissolved P	0.14	0.12	
COD		47.0	43.1
14°-BOD_{32} hrs		0.3	
14°-BOD_5		3.8	
14°-BOD_{10}		5.8	
14°-BOD_{20}		8.8	
14°-BOD_{30}		13.2	
20°-BOD_{32} hrs		1.7	
20°-BOD_5		7.2	
20°-BOD_{10}		11.0	
20°-BOD_{20}		16.8	
20°-BOD_{30}		18.2	

TABLE 7-3. CHERRY STREET BRIDGE, 11 MAY 1974, 12:30-13:10

	Concentration (mg/l)		
Parameter	East @ 10'	Mid @ 13'	West @ 13'
SS	46	44	
TDS		378	373
Total C		43.6	
Organic C		12.0	13.0
Inorganic C		31.6	
Total N		2.00	
Kjeldahl N		0.52	0.40
Ammoniacal N		0.31	
NO_3 N	1.06	1.14	
NO_2 N		0.032	
Total P	0.18	0.16	
Dissolved P		0.11	0.11
COD	35.3	39.2	
14°-BOD_1		1.1	
14°-BOD_5		4.0	
14°-BOD_{10}		5.6	
14°-BOD_{20}		8.0	
14°-BOD_{30}		10.7	
20°-BOD_1		1.9	
20°-BOD_6		6.6	
20°-BOD_{10}		9.0	
20°-BOD_{20}		14.6	
20°-BOD_{30}		15.1	

TABLE 7-4. CHERRY STREET BRIDGE, 12 MAY 1974, 07:30-08:10

	Concentration (mg/l)		
Parameter	East @ 10'	Mid @ 13'	West @ 3'
SS		41	42
TDS	416	416	
Total C	47.7	47.7	
Organic C	13.9	14.9	
Inorganic C	33.8	32.8	
Total N		2.23	
Kjeldahl N	0.42	0.53	
Ammoniacal N		0.22	
NO_3 N		1.45	1.58
NO_2 N		0.030	
Total P		0.15	0.17
Dissolved P	0.11	0.11	
COD		29.4	33.3
14°-BOD_1		0.2	
14°-BOD_5		3.3	
14°-BOD_{10}		4.7	
14°-BOD_{20}		7.4	
14°-BOD_{30}		9.8	
20°-BOD_1		1.4	
20°-BOD_5		6.2	
20°-BOD_{10}		8.0	
20°-BOD_{20}		13.5	
20°-BOD_{30}		13.5	

TABLE 7-5. MOUTH, 11 MAY 1974, 20:15-20:45

	Concentration (mg/l)			
Parameter	East @ 10'	Mideast @ 13'	Midwest @ 16.5'	West @ 6.5'
SS		54	49	45
TDS	381	380	377	
Total C	37.0	36.9	33.4	
Organic C	10.9	10.8	9.4	
Inorganic C	26.1	26.1	24.0	
Total N		3.48	2.91	
Kjeldahl N	0.99	1.26	0.98	
Ammoniacal N		0.84	0.59	
NO_3 N		1.34	1.30	1.26
NO_2 N		0.039	0.036	
Total P		0.24	0.19	0.21
Dissolved P	0.16	0.16	0.11	
COD		48.6	35.2	45.1
14°-$BOD_{32\ hrs}$		0.1	0.4	
14°-BOD_5		3.0	2.9	
14°-BOD_{10}		4.2	4.5	
14°-BOD_{20}		6.9	7.4	
14°-BOD_{30}		13.9	14.3	
20°-$BOD_{32\ hrs}$		1.0	1.2	
20°-BOD_5		4.9	5.4	
20°-BOD_{10}		6.3	6.4	
20°-BOD_{20}		16.6	15.1	
20°-BOD_{30}		20.4	16.4	

TABLE 7-6. MOUTH, 12 MAY 1974, 15:45-16:00

	Concentration (mg/l)			
Parameter	East @ 10'	Mideast @ 13'	Midwest @ 16.5'	West @ 6.5'
SS		45	42	46
TDS	403	415	417	
Total C	44.5	46.6	46.4	
Organic C	14.2	11.7	13.1	
Inorganic C	30.3	34.9	33.3	
Total N		2.39	2.25	
Kjeldahl N	0.78	0.58	0.52	
Ammoniacal N		0.31	0.27	
NO_3 N		1.46	1.42	1.34
NO_2 N		0.038	0.040	
Total P		0.20	0.20	0.23
Dissolved P	0.14	0.10	0.13	
COD		48.6	40.5	44.6
14°-BOD_1		1.5	1.3	
14°-BOD_5		3.9	3.8	
14°-BOD_{10}		5.7	5.3	
14°-BOD_{20}		8.1	7.8	
14°-BOD_{30}		13.4	12.3	
20°-BOD_1		2.0	1.9	
20°-BOD_5		6.1	5.9	
20°-BOD_{10}		9.9	8.9	
20°-BOD_{20}		15.9	15.0	
20°-BOD_{30}		15.9	15.3	

and the size of Toledo's treated wasteloads, there was remarkably little difference in water quality from Perrysburg Bridge to the mouth. Some of the flux at Perrysburg was no doubt sedimented; but the principal explanation of the estuary's rather stable concentration profile is backflow volume. Vastly more water is stored in the lower estuary than at Perrysburg Bridge (see figure 7-18), and much of this enormous incremental volume is lakewater, which is always cleaner than riverwater.

Gradually diminishing TDS concentrations between Perrysburg and the mouth show that riverwater was progressively diluted with lakewater in the estuary: TDS was highest at Perrysburg and lowest at the mouth. During the flush of 12 May, however, the TDS concentration did not change between Cherry Street and the mouth. Jugs that passed Cherry Street on 12 May at 09:25 passed the mouth at 15:30 without having been snagged anywhere en route: Their trajectory, after the powerful flow reversal in the early morning (see figure 7-7), was very well behaved and showed no signs of the stagegraph's bumpy descent. (This disparity between jug movement and descending stagegraph was again seen in September, and leads us to question the accuracy of this structural feature; it is noteworthy, we think, that the Toledo stagegraph often rises smoothly and falls irregularly.) During the flush there was evidently little mixing of riverwater with lakewater near the jugs.

Because the water mass moved so regularly between Cherry Street and the mouth on 12 May, special importance attaches to changes in water quality during that interval (see tables 7-4 and 7-6). SS concentrations at the mouth were slightly higher than at Cherry Street, but it is impossible to apportion this small difference between two likely causes: (1) roiling and scouring of the soft riverbed by the strong flushing currents, and (2) fresh inputs of municipal and industrial wastes. The mouth was dirtier than Cherry Street by every measure of oxygen demand except organic carbon and 20°-BOD_5; this finding supports the widespread contention that organic carbon and 20°-BOD_5 are, by themselves, inadequate indicators of both water quality and oxygen demand: One must always know much more about the water and its oxygen-depletion kinetics than these two measurements could possibly reveal. Cherry Street had higher nitrate concentrations, but all other nitrogen forms were more concentrated at the mouth; total phosphorus (but not dissolved phosphorus) was also higher at the mouth. Although the concentrations did not change much, the fluxes almost certainly increased, because the mouth has a larger cross-sectional area than Cherry Street, and the current velocities were, if anything, somewhat higher at the mouth. Since COD concentrations at the mouth were much higher, the difference in flux must have been very great; furthermore, it would be difficult to attribute this difference to scour, since SS concentrations had scarcely changed, or to lakewater, since the TDS was constant, and lakewater is cleaner than riverwater in any event. The large increase in oxygen demand must be attributed to wastes from lower Toledo.

Although the movement of the water mass was extremely complex during most of our May survey, we will hazard a comparison of the water at the mouth on 12 May with the water at Perrysburg Bridge on 10 and 11 May; the jugs' behavior most of this time was highly irregular. However, some of the Perrysburg water (after dilution and alteration in passage through the lower estuary) had probably reached the mouth by 15:30, 12 May. In most respects the mouth was nearly identical to or cleaner than Perrysburg.

Comparisons must be approached cautiously not only because of hydraulic complexities, but also because several important physical and chemical phenomena (sedimentation, sorption, scour, chemical and biological transformation) may have modified water and its contents: There is undoubtedly more going on in the lower estuary than simple oxygen depletion and the addition of liquid waste. SS at Perrysburg was much higher, and this must be expected: The long riffle, ascending hydrograph, and swift currents all promoted scour, corrasion, and suspension at Perrysburg Bridge; none of these forces obtained (or obtained with anything like equal force) at the mouth. Although COD at Mouth/Mideast was higher than at Perrysburg, at Mouth/Midwest it was lower; note that COD was variable at both the Perrysburg and mouth transects, and much more variable at the mouth (especially on 11 May, as shown in table 7-5, even though TDS, DO, and temperature were horizontally and vertically stable).

Because the concentrations were not drastically different, fluxes at the mouth must have been enormously greater: Current velocity during the flush was about 1 fps. Though we did not measure the current velocity at Perrysburg on 12 May, we did measure it several times on the 10th; it was well below 2 fps at every depth and at every point on the transect, and was often less than 1 fps. Since the concentrations and velocities are comparable, but the mouth's cross-sectional area is many times the area at Perrysburg, the flux at the mouth during the flush must have been many times larger than it was at Perrysburg.

However, the estuary is not always flushing; nor does it often flush as dramatically as it did on 12 May. During long intervals no riverwater leaves the estuary; indeed, large volumes of lakewater flow into the estuary, where they are stored and mixed with riverborne wastes. As figures 7-3 through 7-7 show, millions of cubic ft of lakewater entered the estuary in early May, sometimes very quickly; e.g., on 8 May the stage was elevated by more than 2 ft in eight hours, then fell nearly 3 ft in the next twelve hours. During just five days (8-12 May) the stage dropped nearly 4 ft, and not monotonically: There were large and frequent reversals during its descent.

The estuary's mass balance is easy to conceptualize but nearly impossible to quantify precisely. In the long run (which may be very long), the estuary's net contribution to Lake Erie is composed of flows and fluxes from: (1) the river at Waterville; (2) Grassy Creek, Delaware Creek, Swan Creek, and miscellaneous small freshets; (3) the sewers and treatment plants which discharge into the river below Waterville; and (4) groundwater and diffuse surface runoff from the drainage area below Waterville. The estuary's net outflow is the sum of these four components; its net mass output is not so simple because of sedimentation, bedload transport, and dredging. At riverflows of several thousand cfs, the largest of these components by far is the contribution from Waterville, but it would be a primitive approximation (at best) to use the Waterville discharge for calculating fluxes at the mouth. Nonetheless, if the estuary's flush volume is accurately prorated over time, most of the net outflow must be the Waterville discharge: After all, that is where most of the water comes from. When the estuary's hydraulics have been fully studied, it should be possible to develop methods for calculating fluxes and net discharges at the mouth; and when the dynamics of sedimentation and bedload transport are understood in the lower Maumee, it should be possible to account for the remainder of the river's mass output. Until then, however, one can neither estimate fluxes, nor develop a mass budget, nor have at hand the fundamental tools needed to construct a wasteload allocation for Toledo when the estuary is low and stagnant.

One must consequently beware of falsely attributing the high fluxes seen at the mouth on 12 May to Toledo alone. A great deal of riverwater had been stored in the estuary during early May (no one can say precisely how much), together with the waterborne wastes from the drainage area of the entire Maumee basin. Some of the material that left the estuary on 12 May certainly came from greater Toledo; equally certainly, much of the material came from more distant reaches of the drainage basin. The exact proportions are unknown, and will remain unknowable until the estuary has been diligently researched for several years.

Similar results were obtained in September, when the input of riverwater from Waterville was only a small fraction of what it had been in May, and when the Toledo STP was grossly malfunctioning. Although the jugs moved erratically until the final hours of the September survey and were frequently snagged (which required that they be repeatedly reset), we were able to shepherd them far more carefully than in May because there were no violent storms or small-craft warnings. We are reasonably confident that the jugs' movement in September traced the complex movements of the water mass.

After having erratically meandered for several days (from 21 September until the evening of the 24th), the jugs at last began to move regularly with the flushing currents on the 24th and 25th. Changes in water quality during the flush are therefore extremely significant, because our samples followed the alteration of the water's contents as the estuary was flushed into the lake.

Tables 7-7 and 7-8 summarize the results of the September survey. The jugs were just below the Anthony Wayne Bridge when the flush began; samples #6 through #12 were taken behind the jugs as they travelled downriver. Their trajectory was smooth and well-behaved; it showed only one possible sign of the stagegraph's bumpy descent. Although the stagegraph began to fall at 16:00 on the 24th, the jugs were travelling upriver at 17:35; this deep reverse flow (the jugs on 20' lines led the

TABLE 7-7.

KEY TO SAMPLING STATIONS IN THE MAUMEE RIVER SURVEY, SEPTEMBER 1974

Sample Number	RM	Sample Collection Point
No. 1	14.1	Perrysburg Bridge, between Piers #3 and #4, @ 2' depth
No. 2	11.4	Interstate 80/90 Bridge, Pier #4, @ 5' depth
No. 3	6.9	DiSalle Bridge, Pier #5, @ 6' depth
No. 4	6.9	DiSalle Bridge, Pier #2, @ 2' depth
No. 5	6.9	DiSalle Bridge, Pier #2, @ 11' depth
No. 6	5.4	Anthony Wayne Bridge, Middle, @ 10' depth
No. 7	4.6	Cherry Street, Middle, @ 10' depth
No. 8	3.6	Craig Bridge, Middle (Pier #3), @ 8' depth
No. 9	3.6	Craig Bridge, West (Pier #5), @ 10' depth
No. 10	1.3	Toledo Terminal Railroad Bridge, Pier #3, @ 10' depth
No. 11	0	Mouth, Middle, @ 15' depth
No. 12	0	Mouth, West, @ 6' depth

TABLE 7-8.

MAUMEE RIVER SURVEY, SEPTEMBER 1974: LABORATORY RESULTS

Test Parameter	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Date (1974)	9/20	9/21	9/22	9/23	9/23	9/24
Time	19:00	14:45	13:25	09:05	09:10	14:15
SS (mg/l)	38	76	64	58	64	48
TDS (mg/l)	532	512	455	527	467	446
Total C (mg/l C)	48	47	47	45	47	46
Inorganic C (mg/l C)	24	23	26	25	24	23
Organic C (mg/l C)	24	24	21	20	23	23
COD (mg/l)	41	35	31	47	28	24
Total N (mg/l N)	0.957	0.752	1.132	0.793	1.110	1.172
Kjeldahl N (mg/l N)	0.69	0.58	0.65	0.24	0.46	0.46
Ammoniacal N (mg/l N)	0.17	0.11	0.06	0.09	0.07	0.15
NO_3 N (mg/l N)	0.08	0.05	0.40	0.44	0.56	0.54
NO_2 N (mg/l N)	0.017	0.012	0.022	0.023	0.020	0.022
Total P (mg/l P)	0.30	0.32	0.25	0.25	0.26	0.22
Dissolved P (mg/l P)	0.06	0.19	0.17	0.18	0.19	0.15
Fecal Coliform Bacteria (Organisms/100 ml)	78	158	140	220	290	750
20°-BOD_1 (mg/l)	1	2	<1	<1	<1	1
20°-BOD_2 (mg/l)	3	2	2	1	1	2
20°-BOD_3 (mg/l)	4	3	2	2	2	2
20°-BOD_4 (mg/l)	5	5	3	2	2	2
20°-BOD_5 (mg/l)	6	5	3	2	2	2
20°-BOD_{10} (mg/l)	9	8	4	4	4	3
20°-BOD_{20} (mg/l)	11	9	5	5	5	4
20°-BOD_{30} (mg/l)	13	13	7	6	6	4

TABLE 7-8 (cont'd)

Test Parameter	No. 7.	No. 8	No. 9	No. 10	No. 11	No. 12
Date (1974)	9/24	9/25	9/25	9/25	9/25	9/25
Time	22:25	02:40	03:15	08:10	09:25	09:45
SS (mg/l)	36	58	42	56	46	80
TDS (mg/l)	469	395	420	336	318	345
Total C (mg/l C)	40	43	44	39	38	40
Inorganic C (mg/l C)	19	20	20	19	17	18
Organic C (mg/l C)	21	23	24	20	21	22
COD (mg/l)	16	27	16	24	27	27
Total N (mg/l N)	1.504	1.527	1.680	1.810	2.150	2.430
Kjeldahl N (mg/l N)	0.58	0.55	0.42	0.64	1.08	1.09
Ammoniacal N (mg/l N)	0.26	0.22	0.42	0.48	0.50	0.71
NO_3 N (mg/l N)	0.63	0.68	0.79	0.53	0.40	0.47
NO_2 N (mg/l N)	0.034	0.077	0.050	0.160	0.170	0.160
Total P (mg/l P)	0.20	0.22	0.20	0.21	0.22	0.30
Dissolved P (mg/l P)	0.15	0.17	0.20	0.13	0.16	0.13
Fecal Coliform Bacteria (Organisms/100 ml)	780	990	490	1050	80	1840
20°-BOD_1 (mg/l)	1	1	<1	1	1	1
20°-BOD_2 (mg/l)	1	2	1	2	2	2
20°-BOD_3 (mg/l)	1	2	1	2	2	4
20°-BOD_4 (mg/l)	2	2	1	3	3	5
20°-BOD_5 (mg/l)	2	2	2	3	4	6
20°-BOD_{10} (mg/l)	2	3	2	4	4	6
20°-BOD_{20} (mg/l)	4	4	3	5	6	8
20°-BOD_{30} (mg/l)	5	4	4	6	7	9

pack during the flow reversal) was brought about by the rising stagegraph in the early afternoon (see figure 7-14). It took several hours for the flow-reversal wave to travel upriver; stage fluctuations at the mouth cause (and therefore precede) the waves which traverse the estuary. From 18:30 until the jugs passed the mouth, they were snagged only once: at the west end of Craig Bridge (RM 3.6) at 02:40 on the 25th. This single snag may have been due to the strong west and southwest winds, but it may also have been caused by the small flow reversal at the mouth between 01:00 and 02:00 on the 25th. As the sample-collection times in table 7-8 show, the jugs accelerated as they travelled between Toledo Terminal Railroad Bridge and the mouth. The stagegraph (figure 7-15) does not explain the acceleration.

Because of stratification, two samples were taken at Craig Bridge (samples #8 and #9) and two were taken at the mouth (samples #11 and #12). The water was not thermally stratified on the 25th at Craig Bridge: It was vertically stratified with respect to conductivity and horizontally stratified with respect to DO (see Appendix 1). Together with the evidence provided by the stagegraph and by the jugs' snagging, the stratification at Craig Bridge on the 25th may be attributed to a true flow reversal. The vertical and horizontal stratification at the mouth on the 25th cannot be explained by the jugs or by the stagegraph. The acceleration of the flushing currents may account for the horizontal stratification; but we have no plausible explanation for the vertical stratification.

It is significant that the river was vertically stratified with respect to temperature at Craig Bridge at noon on the 24th, when the estuary was suddenly and strongly in reverse flow, but unstratified with respect to temperature during the flush (when the flow reversal could not have amounted to much; see figures 7-14 and 7-15). The thermal stratification on the 24th must be attributed to the cooling-water discharge from the Acme powerplant; on the 25th, however, when the estuary had been steadily flushing for several hours, no large thermal effect could be seen. During the flush, the water at Craig Bridge was no more than 1° C warmer than at Cherry Street; but during the steep reversal at midday on the 24th, the water at Craig Bridge was as much as 4.4° C warmer than the water at Cherry Street. The temperature at the Acme intake at 12:30 on the 24th was 20° C; from the intake to the tip of the jetty which separates Acme's outfall ditch from the Maumee, the water temperature rose steadily to 26.5° C. Even this highest temperature is well below the maximum permitted by Ohio's WQS (viz. 32.2° C); but the temperature increment is greater and more extensive than the 2.8°, 12-acre mixing zone which the standards allow. If the estuary's DO were safely above 5 mg/l, the slight warming of the river by Acme's huge outfall would be less important than it is. However, the warm outfall seems to be responsible for the DO's dropping below the already substandard concentration which we regularly observed at Cherry Street. When the estuary is very low and stagnant, the temperature effect attributable to the Acme plant will undoubtedly be much larger, and the estuary's DO will be even more seriously degraded.

The Acme plant's effect on the river is not entirely limited to the warm outfall. The plant's sludge pits feed a gushing black discharge and a corrosive yellow leachate into the river. The pH of the leachate was 2.6, which explains why a trench had been cut through the bottom of the 3/8th-inch, cast-iron outfall pipe.

The principal changes in the water mass during the September survey are as follows:

1. Conductivity and TDS decreased almost monotonically between Perrysburg and the mouth; both sets of measurements showed a slight

increase at the beginning of the flush, then a steep decrease as the estuary spilled into the lake. TDS and conductivity were in excellent agreement. These measurements show (once again) that riverwater was progressively mixed with lakewater in the estuary.

2. SS was highly erratic: It was sensitive to both the changing character of the riverbed and to scouring by the flushing currents. The concentration more than doubled between Perrysburg Bridge and the I-80/90 Bridge; this must be attributed to the descending Waterville hydrograph and to the riverbed's changing from crystalline rock in the riffles above Perrysburg to soft clay in the estuary. SS concentrations fell steeply during the generally calm days before the flush began; but when the flush started, the concentrations jumped (compare samples #7 and #8 in table 7-8) as the flushing currents began to scour the sediments. Between Craig Bridge/Middle and Mouth/Middle (samples #8 and #11) the concentrations dropped irregularly; but SS concentrations at Mouth/West (sample #12), which is affected by the STP, were the highest we observed, and reflect the STP's poor operation. The declining SS concentrations between Craig/Middle and Mouth/Middle probably reflect the ever-increasing proportion of lakewater, but this explanation is not entirely satisfactory since the flushing currents were still very strong.

3. Concentrations of fecal coliforms increased enormously in Toledo. They were very sensitive to stratification (compare samples #8 and #9, and samples #11 and #12) and may have been sensitive to stagnation (compare sample #3, taken on the 22nd, with samples #4 and #5, taken on the 23rd, all at Disalle Bridge; the jugs scarcely moved during that interval -- they meandered aimlessly with the sloshing estuarine currents). The flagitious bacterial concentration at Mouth/West (sample #12) suggests that, in addition to its other difficulties in September, the STP was not achieving adequate disinfection. Although

bacterial concentrations were highest near the STP, they were too high throughout downtown Toledo. The steep increase between DiSalle and Anthony Wayne may be attributed to malfunctions in any of the several combined-sewer regulators in the vicinity; the regulators must have been malfunctioning because the weather had been very dry for several months, and no more than 0.2 inch of rain had fallen in a week. The sewer outfalls we examined in September were not gushing, as they did in May; but they were always dribbling, despite the drought.

4. All forms of BOD were very well behaved and admirably consistent: They followed a sag curve that closely agrees with the DO sag curve. Highest DO and highest BOD were seen at Perrysburg; lowest DO and lowest BOD were at Cherry Street and Craig Bridge; both DO and BOD were up again at Toledo Terminal Bridge and the mouth. Note that all BODs were incubated at 20° C because the water temperature was approximately that throughout our survey (see Appendix 1). Contrary to usual expectation, there was no correlation between BOD and bacterial concentrations (owing to the leaky sewers, no doubt); but BOD and SS were in rather good agreement: Both were lowest around Cherry Street, highest near the extremities of the estuary, and transitional at intermediate points. SS was much more sensitive than BOD to current velocities and to stratification.

5. COD behaved much like BOD, though not so smoothly. Once again concentrations were highest at Perrysburg, lowest at Cherry Street, and high again at the mouth. COD was very sensitive to stratification at DiSalle and Craig, but anomalously insensitive to stratification at the mouth -- quite different from its behavior in May.

6. Total carbon, inorganic carbon, and organic carbon changed very little. Inorganic carbon was the most variable of the three forms.

All forms were less concentrated in the lower estuary and at the mouth than they had been at either Perrysburg or I-80/90.

7. Total phosphorus behaved much like COD and SS, but less erratically: It was high at Perrysburg and I-80/90, lowest at Cherry Street, and high again at Mouth/West (owing to the malfunctioning STP). Dissolved phosphorus was extremely low at Perrysburg, but little changed from I-80/90 to the mouth. Since total phosphorus was much the same at I-80/90 as it had been at Perrysburg, we wonder whether particulate phosphorus might have been transformed into dissolved phosphorus in the estuary; desorption or autolysis could be called to account.

8. Total nitrogen, ammoniacal nitrogen, and nitrite nitrogen behaved much like the bacterial concentrations: They were low upriver of DiSalle, and increased greatly in the lower estuary. Ammoniacals more than tripled between Anthony Wayne and Mouth/Middle, and more than quadrupled between Anthony Wayne and Mouth/West. Kjeldahl nitrogen was high at Perrysburg, lower (but variable) between I-80/90 and Craig, and highest at the mouth (where it was unaffected by stratification). Nitrate was lowest at Perrysburg and I-80/90, highest at Craig, and high everywhere from DiSalle to the mouth; the nitrate profile is unlike any of the others. It is noteworthy that nitrate was not highest at Perrysburg (which is closest to the agricultural lands and to the oxygenating riffle); it was highest at Craig (which is set amid Toledo's thermal and deoxygenating wastes).

The unusual behavior of nitrates in September bears comparison with the very different pattern in May, when they were (as might have been expected) highest at Perrysburg and lowest at Cherry Street. The estuary was more stagnant in September, there was far less landwash (owing to the drought), and there was much less fertilizer left on the fields at harvest-time than there had been in the Spring. There is no doubting that vastly more nitrate entered the estuary in May than in September, nor that vastly more nitrate was flushed out (concentrations, volumes, and velocities were all larger in May than in September). The high nitrate concentrations in the lower estuary in September cannot be readily explained: They certainly cannot be traced to the upper estuary or to rural landwash. Perhaps conditions in the estuary and in the sewers promoted more nitrate formation (through a combination of longer detention times, autoxidation, and microbial metabolism) in September than in May. The microbiology of the sewers seems a particularly promising line of investigation.

It must be borne in mind, however, that the estuary was colder, more oxygenated, and more unstable (hence more thoroughly and frequently flushed) in May than in September; estuarine stagnation times in September may have been long enough for some nitrates to have been formed from the plentiful organic wastes in the river. There are no fertilizer factories or nitric-acid plants in Toledo. The only possible sources of nitrates (aside from sewage) are the large agricultural supply houses at the head of the navigation channel. Large quantities of fertilizer are handled at these houses, but they would have had to have spilled colossal quantities of the stuff to be called to account for the high nitrate levels we saw in the lower estuary. To our knowledge, nothing of the kind occurred, and we were on the river, near the head of the navigation channel, for several days and nights in September. The high nitrate concentrations for September notwithstanding, nitrate N accounted for much less than half the total N during the September flush, whereas in May nitrate N accounted for over half the total N. This difference, we believe, must be attributed to rural landwash and to the erratic STP.

The amount of phosphorus which entered the estuary was far higher in May than in September (see table 1-1). The concentration of total P during both flushes was nearly the same, but the flush volume was larger in May than in September (compare figure 7-4 with figures 7-14 and 7-15); hence the Maumee contributed more phosphorus to Lake Erie in May than in September -- despite the fact that the Toledo STP was operating reasonably well in May but was having a terrible time of it in September. These observations suggest once again how important it is to consider landwash when accounting for the phosphorus which enters Lake Erie. Notice also that the May flush contributed more solids (especially dissolved solids) to the lake than the September flush. And more carbon. And more nitrogen. And more COD.

And more BOD, especially long-term BOD. The concentration of $20°\text{-BOD}_{30}$ in the May flush was nearly double the September concentration. Figures 7-19 and 7-20 give the BOD rate curves for the May and September surveys. Because the May water temperature was about 14° C, BOD was run at two temperatures: the actual water temperature (14°), and the standard 20°. In September the actual water temperature was about 20°, so we had one less analysis to do. All samples were incubated in the dark (since there was no sign of a diurnal photosynthetic effect), and all were identically seeded with sludge from the Toledo STP (which ensures strict comparability among the samples). The rate curves for May and September are dramatically different. The May BOD was stronger, higher, and longer-acting than the September BOD. The 14°-BOD at Cherry Street and the mouth in May was much higher than the 20°-BOD at those stations in September. One would be hard pressed to find more persuasive evidence of the upriver heritage, its magnitude, its significance in relation to Toledo, and its contribution to the degradation of Lake Erie.

FIGURE 7-19.

14°-BOD AND 20°-BOD RATE CURVES:
MAUMEE RIVER, 10-12 MAY 1974

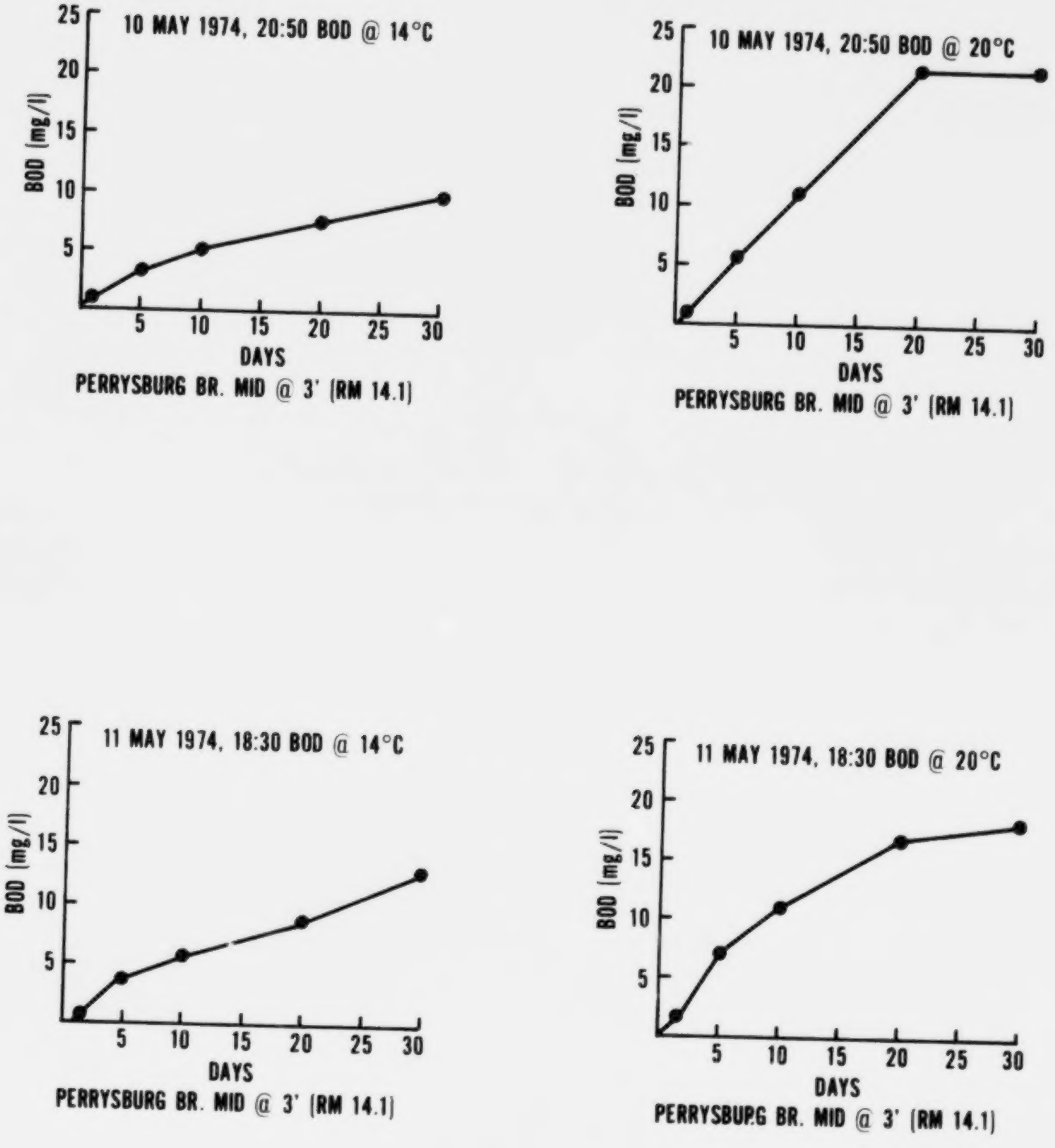
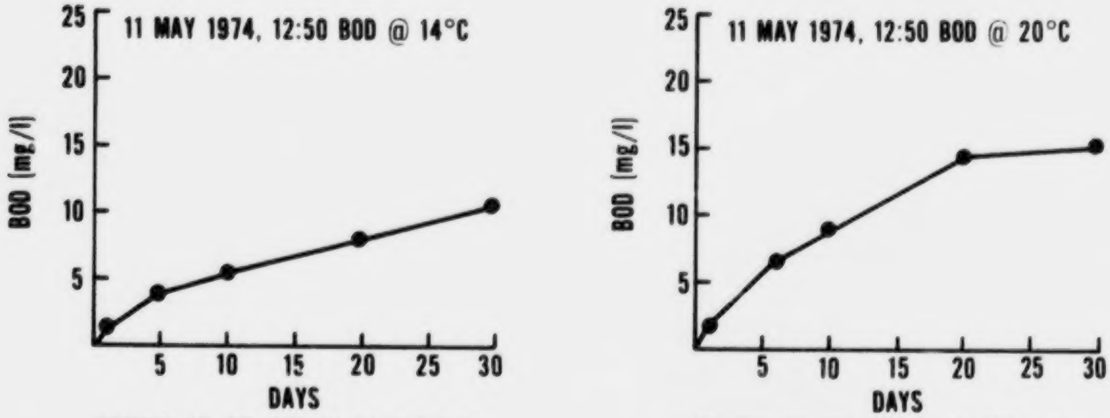
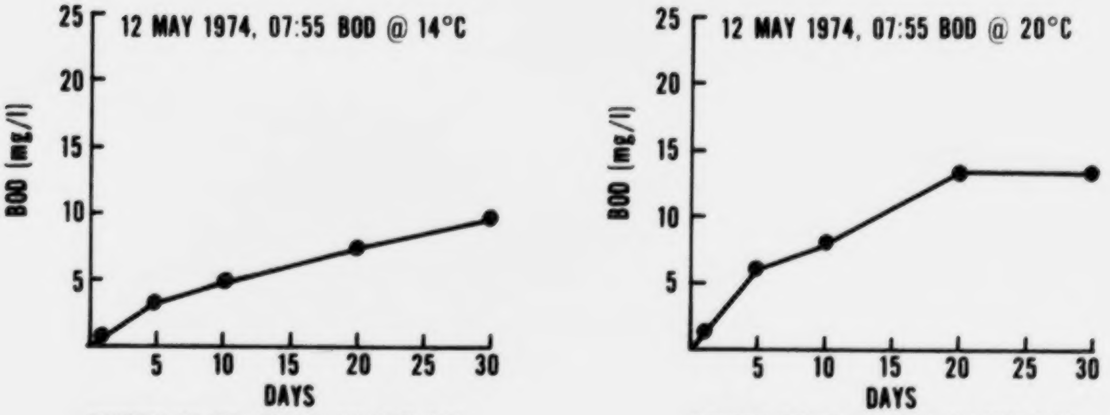


FIGURE 7-19 (cont'd)



CHERRY ST. BR. MID @ 13' (RM 4.6)

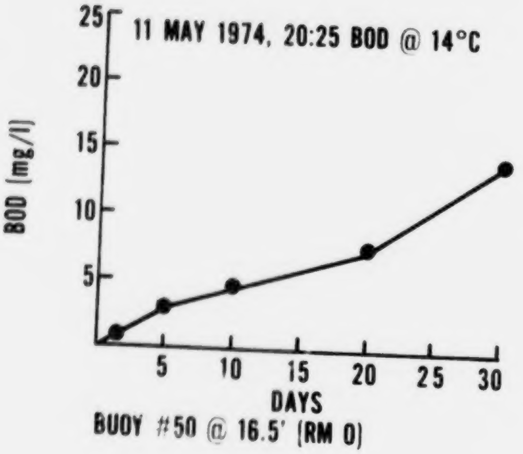
CHERRY ST. BR. MID @ 13' (RM 4.6)

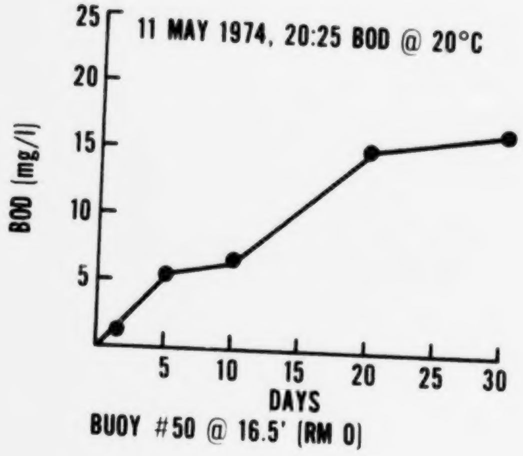


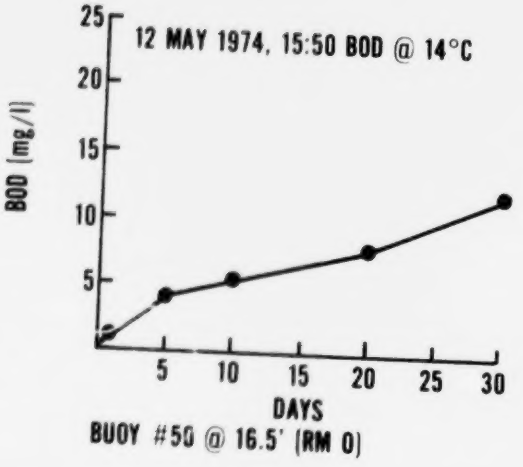
CHERRY ST. BR. MID @ 13' (RM 4.6)

CHERRY ST. BR. MID @ 13' (RM 4.6)

FIGURE 7-19 (cont'd)







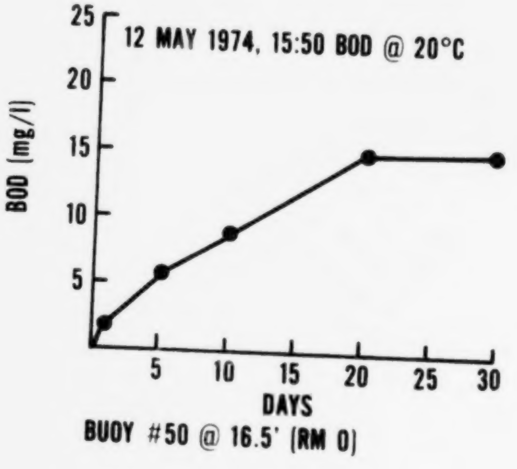


FIGURE 7-19 (cont'd)

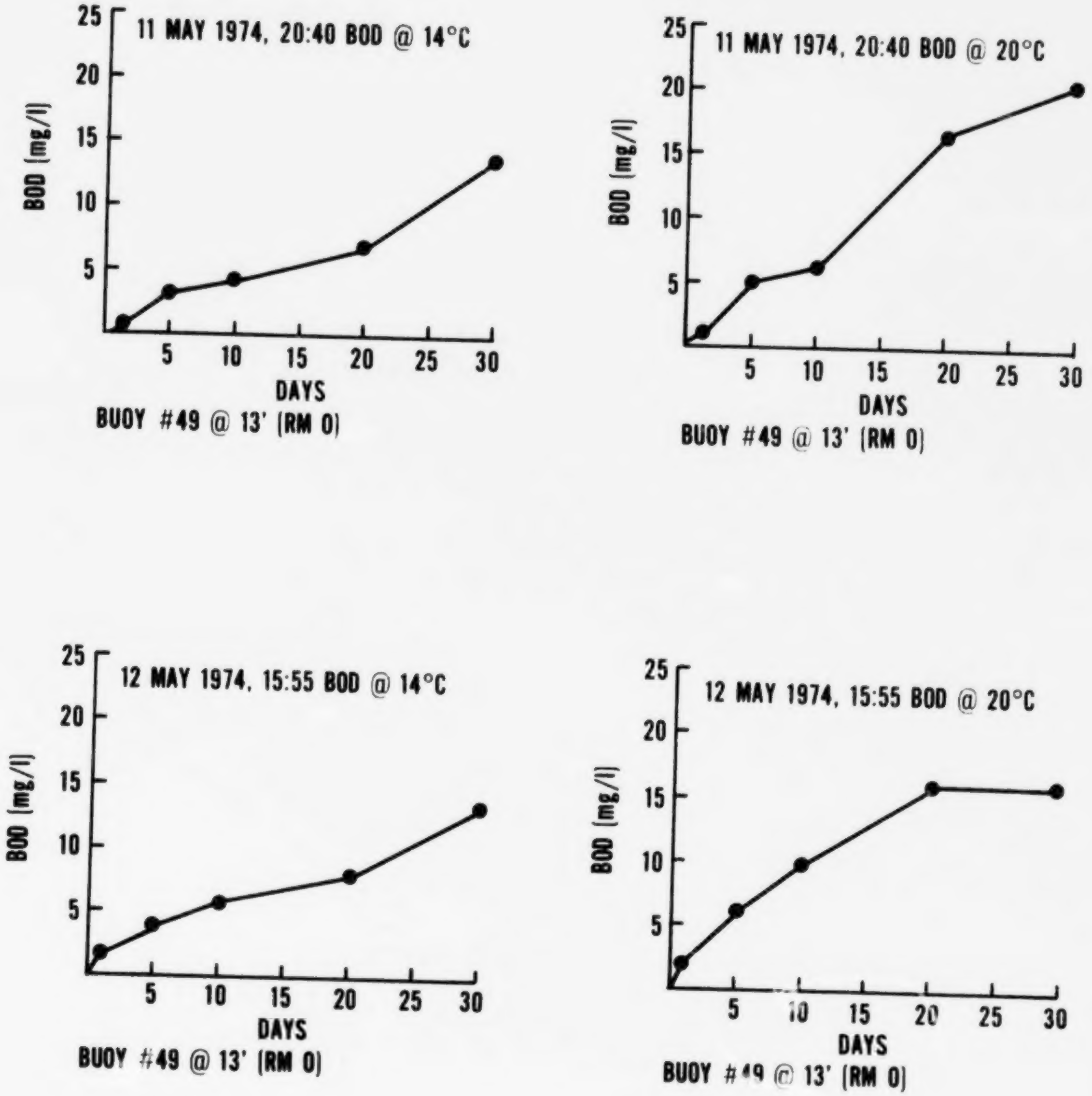
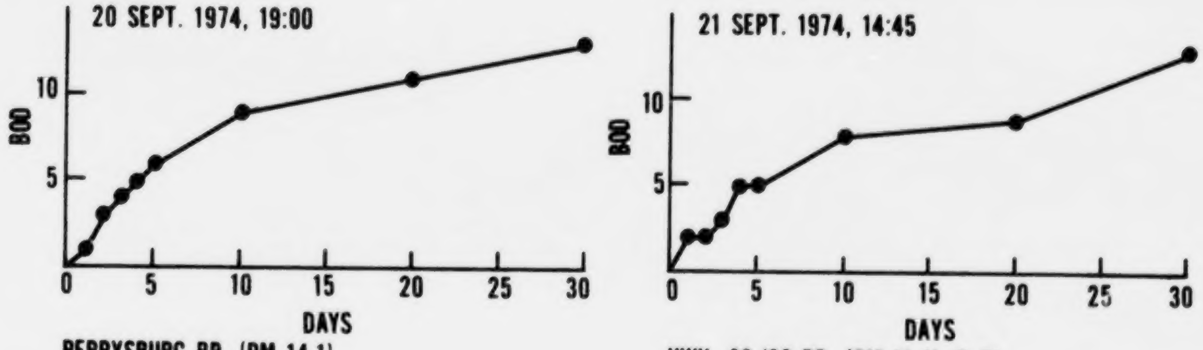


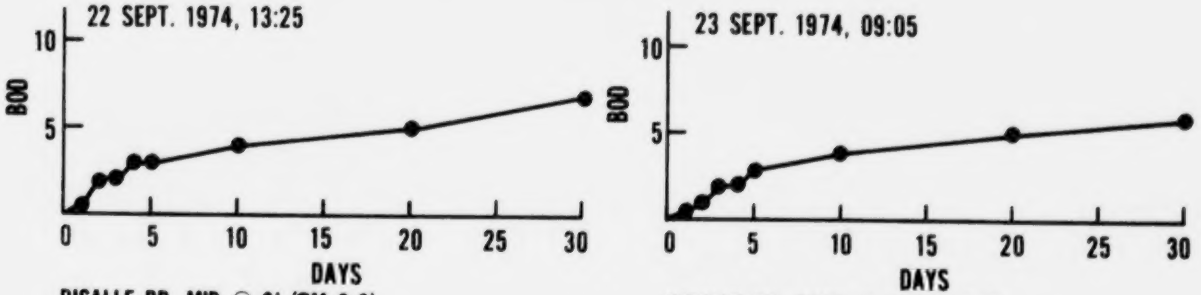
FIGURE 7-20.

20°-BOD RATE CURVES:
MAUMEE RIVER, 20-25 SEPTEMBER 1974



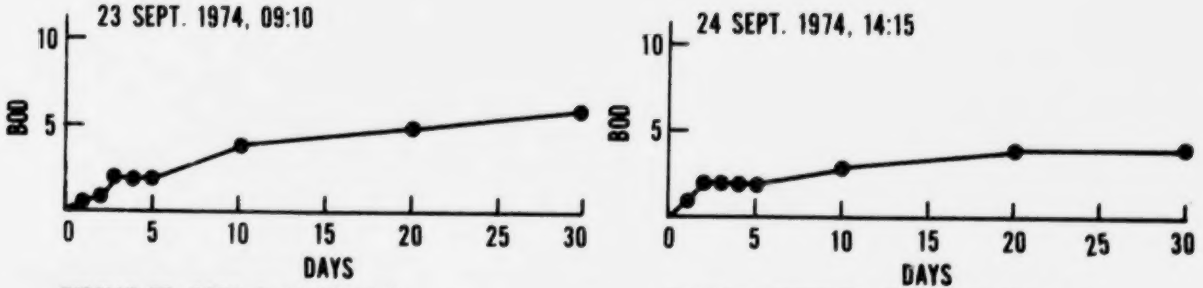
PERRYSBURG BR. (RM 14.1)

HWY. 80/90 BR. (RM 11.4) @ 5'



DISALLE BR. MID @ 6' (RM 6.9)

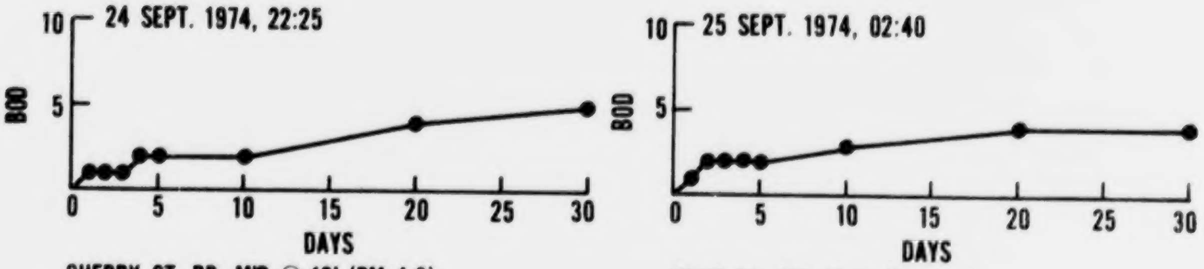
DISALLE BR. EAST @ 2' (RM 6.9)



DISALLE BR. EAST @ 11' (RM 6.9)

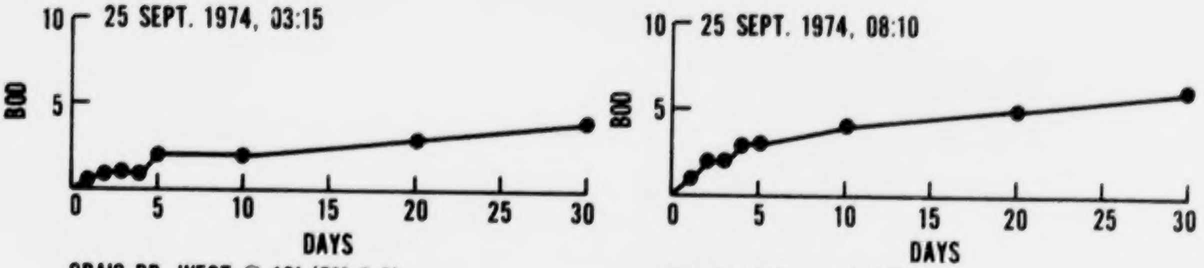
ANTHONY WAYNE BR. MID @ 10' (RM 5.4)

FIGURE 7-20 (cont'd)



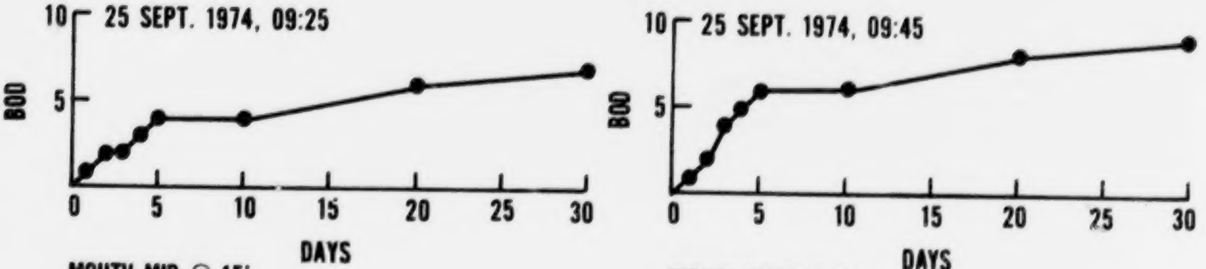
CHERRY ST. BR. MID @ 10' (RM 4.6)

CRAIG BR. MID @ 8' (RM 3.6)



CRAIG BR. WEST @ 10' (RM 3.6)

TTR BR. MID @ 10' (RM 1.3)



MOUTH MID @ 15'

MOUTH WEST @ 6'

This pair of surveys suggests that both rural landwash and deficient waste-management in Toledo are responsible for poor water quality in the estuary. Our analysis suggests that landwash is quantitatively far more important, and is therefore the more meaningful measure of the Maumee's effects on Lake Erie: Toledo's effects, though large, are more localized. One can readily imagine a compounding of these two elements that would set off an appalling deterioration of the estuary. Suppose that the runoff from a severe regional storm were trapped in the estuary when lake levels were low and stable; and suppose that the STP should have a mishap comparable to the one in September 1974; and suppose that Toledo's sewers behaved as they usually do in a storm; and -- since we are pandering to a taste for horror -- suppose that all this happened in a hot summer. Under these conditions, we believe, the estuary would be at risk of utter degradation, and the water would become ever more foul in proportion to the stagnation time.

None of these suppositions is fanciful: Each of them has occurred. All of them probably occurred in the early 1960's, perhaps all at once. So far as is known, no one died of water pollution then, and it is doubtful that anyone would die of it should these conditions recur. The pioneers whose awesome labors drained the swamps of northwestern Ohio are to be thanked for the prevention of sickness and death under such climatic circumstances. Pollution control is not exclusively concerned with public health: It is concerned with a better environment and with the control of factors which are responsible for its deterioration. We therefore urge that these factors be evaluated more judiciously, with a greater appreciation for what can (and cannot) be controlled. Landwash, estuarine stagnation, lake stages -- these are matters that have scarcely been considered in current plans for improving the Maumee estuary. The citizens of greater Toledo deserve that much, at least, and will be ill-served if they are not. For their part, Toledoans would be well-advised to acquire the simple decencies of an adequate sewer system and reliable waste treatment.

8. SEDIMENT SAMPLING

Before we had delved sufficiently into the history of the lower Maumee River, we proposed taking deep cores of the sediments, then examining them, stratum by stratum, to document chemical differences among them. Unfortunately, the lower river has been continuously disturbed for at least 100 years: disturbed by extensive sand and gravel dredging, the creation and maintenance of a deep navigational channel, excavations for landfills, bank straightening, and rerouting of tributaries (e.g., Duck Creek was "moved" when the Port of Toledo constructed its Presque Isle facilities). Accurate records have not been kept. One can only say for sure that it would have been foolhardy to draw any historical inferences from cores taken in such a disturbed area.

We nevertheless felt that some attention should be given to at least the surficial sediments. Accordingly, we undertook a brief sediment-sampling program on 19 May 1974. Ten samples were collected with a Petersen dredge (which has the advantage of retaining almost all the entrapped solids); the dredge took a sample of one square foot. The model we used was equipped with heavy weights (for extra penetration); care was taken to lower the dredge gently, to avoid disturbing the very fine materials. Large inclusions (stones, twigs, and miscellaneous debris) were removed immediately. The dredge's contents were dumped into a bucket which was freshly washed with river water for each sample. Material sufficient to fill a one-quart Mason jar was taken from the bucket. The Mason jars were also freshly washed with river water just before being filled. A few ml of saturated bichloride of mercury were stirred into each Mason jar, to prevent biological activity. The Mason jars were stored in a closed ice-chest as a further precaution. All samples were collected between 09:00 and 14:00 on 19 May, and were delivered to the analytical laboratory at 15:30, where they were immediately transferred to cold storage. Analytical methods are referenced in section 9.

Table 8-1 identifies the samples. Intense storm activity had swollen the river during the middle of May: Flows were greater than 10,000 cfs from 13 May until 21 May. The absolute peak of the May hydrograph (20,100 cfs) occurred on the day of our sediment-sampling program, 19 May. The weather was cool and rainy during the early morning, but turned fair and warm by mid-afternoon. There was a strong backflow from the bay until mid-morning, when the currents suddenly reversed and precipitously accelerated. The water was very rough: Small craft warnings were up most of the day. The river was more turbid than we had ever seen it: There was undoubtedly a great deal of scouring and corrasion.

Extremely rough water made it impossible to take samples at Disalle Bridge (Highway 75), and the area around Perrysburg Bridge was scoured as clean as a hospital sink. Flows over Providence Dam were much too violent to permit taking samples anywhere but at the bank, and we are not satisfied with the sample we finally collected (which required a great deal of digging and scooping by hand). We must point out that sample #3 (at the coal docks) was intentionally taken very close to shore so that the washout of coal fines could be fully represented; the water all around these docks is laden with chips, fragments, and fine powders of coal.

Chemical analysis of these ten samples reveals grossly polluted conditions: These are certainly not innocent clays. Table 8-2 summarizes our findings. The mouth of Otter Creek (sample #1) has sediments worthy of a sewer; they show the effects of the refinery discharges (SOHIO and Sun Oil) and of sludge from Toledo's waterworks. In plain point of fact, Otter Creek is used for nothing but waste dumping, so that one should not be too surprised by these results. These sediments head the list for COD and total phosphorus, and are close competitors for top honors in total nitrogen, oils, and grease.

Table 8-1. Identification of Maumee Basin Sediment Samples: 19 May 1974

Sample Number	Time	Water Depth (ft)	Location
1	09:10	2.5	Mouth of Otter Creek, midstream
2	09:20	4.5	Mouth of Duck Creek, midstream
3	09:35	27.	Coal Dock, 100 feet from end of first jetty east of Duck Creek, 5 ft. from shore
4	09:40	37.	Maumee Mouth, middle of the navigation channel, halfway between Buoy #49 and Buoy #50
5	09:50	26.	Maumee Mouth, west of navigation channel, at unnumbered White Buoy, 150 ft. east of Coast Guard slip
6	10:55	18.	Cherry St. Bridge, East; just upriver of the second arch from the east bank
7	11:00	35.	Cherry St. Bridge, Middle; just upriver from the lift-span over the navigation channel
8	11:05	30.	Cherry St. Bridge, West; just upriver of the second arch from the west bank
9	11:10	12.	Swan Creek, Mouth; 10 ft. upstream from black iron bridge at foot of Monroe St.
10	14:00	0.5	Providence Dam @ Grand Rapids, 2 ft. from west bank, 100 ft. upriver from the dam

Table 8-2. Analysis of
Maumee Basin Sediments: 19 May 1974

	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 7	NO. 8	NO. 9	NO. 10
TIME	09:10	09:20	09:35	09:40	09:50	10:55	11:00	11:03	11:10	14:00
DEPTH (feet)	2.5	4.5	27	GT 30	26	18	GT 30	30	12	0.5
TEST PARAMETERS										
DRY SOLIDS (%)	40.1	76.2	40.2	36.3	35.0	39.7	47.7	44.9	46.0	59.2
CHEMICAL OXYGEN DEMAND (mg/kg dry solids)	157,000	30,900	98,900	23,000	71,600	94,300	57,300	90,700	125,000	61,900
PHOSPHORUS, TOTAL (mg P/kg dry solids)	219	2.04	1.99	1.25	1.84	1.73	0.83	2.72	2.77	2.06
PHOSPHORUS, ACID HYDROLYZABLE (mg P/kg dry solids)	7.01	1.24	1.16	1.25	1.07	1.73	0.83	1.85	2.77	2.06
KJELDAHL NITROGEN (mg N/kg dry solids)	477	44.3	540	374	446	246	243	407	459	200
AMMONIA NITROGEN (mg N/kg dry solids)	234	7.70	195	154	166	88.5	139	165	280	7.54
NITRATE NITROGEN (mg N/kg dry solids)	4.52	1.18	9.51	3.63	2.82	3.00	1.91	0.83	2.62	2.39
NITRITE NITROGEN (mg N/kg dry solids)	1.53	0.34	0.59	0.71	0.72	0.81	0.30	0.17	0.49	0.26
OILS & GREASE (mg/kg dry solids)	12,950	764	6,845	13,310	1,233	1,389	1,305	2,578	7,311	793
CYANIDE, TOTAL (mg CN^-/kg dry solids)			0.24							

Sediments at the mouth of Duck Creek (sample #2) put the Otter Creek sediments in perspective. These two creeks flow only a few yards apart, and both flow through the heavily industrialized area near the east bank of the river. However, Duck Creek receives no refinery wastes, and generally receives a much smaller share of the waterworks' sludge; furthermore, the present mouth of Duck Creek is less than 20 years old: The lower reaches of the creek were moved when the Port of Toledo built its Facility #2. Hydrology and geology cannot account for the spectacular differences between the Otter Creek and Duck Creek sediments; industrial and municipal wastes can.

Samples 3, 4, and 5 were taken across the mouth of the river, and all three are in dredged areas, but sample #3 was taken very close to the edge of the coal docks. As might have been expected, sample #3 has much higher COD and total nitrogen than its sister samples, and somewhat more phosphorus; it also has a walloping 0.24 mg/kg of cyanide ion, which is consistent with the observation of coal fines in the water and in the sediments. Cyanide is commonly found in coal that has been exposed to heat during its formation, in later mine fires, or in coking. (The area around Interlake's riverfront may also show high concentrations of cyanide in the sediments because of the plant's busy coke ovens.) Sample #4, taken in the middle of the navigation channel at the river's mouth, has lower COD, total phosphorus, and total nitrogen than its sister samples, but it has much higher concentrations of oils and grease. The very high oil value does not come from a chance clump in the sample: The analysis was repeated several times, and the culprit is a light oil which is thoroughly mixed through the sample. Although sample #5 is closer to the STP than either of its sister samples, it is cleaner than sample #3, and contains much less oil than sample #4. Compared to the relatively discharge-free area at the mouth of Duck Creek (sample #2), however, it is high in COD, and very high in all forms of nitrogen, especially the reduced forms.

Samples 6, 7, and 8 form a transect of the river at Cherry Street Bridge. The east sample (#6) is outside the limits of dredging for the navigation channel; #7 (middle) is squarely in the middle of the channel, and #8 is at the channel's western extreme (and therefore much closer to the leaky sewers on Toledo's downtown west side). COD and phosphorus are considerably lower in midchannel than in the east and west sediments, but the west sediments (#8) are appreciably higher in phosphorus, nitrogen, and oils than its neighbors to the east.

The mouth of Swan Creek (#9) is in most ways as badly polluted as the mouth of Otter Creek (#1). It takes first prize for nitrogen, owing largely to the very high ammonia concentration. In every respect, Swan Creek's sediments are more severely polluted than those of Cherry Street West (#8), its nearest neighbor (they are less than 3,000 feet apart). An excellent account of erosion and sedimentation problems in Swan Creek has been prepared by Earthview, Inc.[1]

The unsatisfactory sample taken at Providence Dam (approximately RM 35) is not entirely without interest. Especially notable are its high COD (higher than either of the two sampling points in Toledo's navigation channel: samples #4 and #7) and its rather high phosphorus. It does not compare favorably with the mouth of Duck Creek (Sample #2): It is considerably higher in COD and Kjeldahl nitrogen, and quite similar in all other respects except in its percentage of dry solids and its content of acid-hydrolyzable (i.e., loosely bound) phosphorus.

---

[1] EARTHVIEW, INC. (April 1973). Flooding and Erosion Related to Urbanization: Swan Creek Watershed, Lucas County, Ohio. Available from George R. Kunkle, President, Earthview, Inc., 316 Colton Building, Madison & Erie, Toledo, Ohio 43624.

Sediments at the mouth of Duck Creek (sample #2) put the Otter Creek sediments in perspective. These two creeks flow only a few yards apart, and both flow through the heavily industrialized area near the east bank of the river. However, Duck Creek receives no refinery wastes, and generally receives a much smaller share of the waterworks' sludge; furthermore, the present mouth of Duck Creek is less than 20 years old: The lower reaches of the creek were moved when the Port of Toledo built its Facility #2. Hydrology and geology cannot account for the spectacular differences between the Otter Creek and Duck Creek sediments; industrial and municipal wastes can.

Samples 3, 4, and 5 were taken across the mouth of the river, and all three are in dredged areas, but sample #3 was taken very close to the edge of the coal docks. As might have been expected, sample #3 has much higher COD and total nitrogen than its sister samples, and somewhat more phosphorus; it also has a walloping 0.24 mg/kg of cyanide ion, which is consistent with the observation of coal fines in the water and in the sediments. Cyanide is commonly found in coal that has been exposed to heat during its formation, in later mine fires, or in coking. (The area around Interlake's riverfront may also show high concentrations of cyanide in the sediments because of the plant's busy coke ovens.) Sample #4, taken in the middle of the navigation channel at the river's mouth, has lower COD, total phosphorus, and total nitrogen than its sister samples, but it has much higher concentrations of oils and grease. The very high oil value does not come from a chance clump in the sample: The analysis was repeated several times, and the culprit is a light oil which is thoroughly mixed through the sample. Although sample #5 is closer to the STP than either of its sister samples, it is cleaner than sample #3, and contains much less oil than sample #4. Compared to the relatively discharge-free area at the mouth of Duck Creek (sample #2), however, it is high in COD, and very high in all forms of nitrogen, especially the reduced forms.

9. ANALYTICAL METHODS

All the water and sediment samples were analyzed at Jones & Henry Laboratories, Inc., of Toledo. The methods are referenced below; all are approved by the U. S. EPA. No water or sediment sample was more than a few hours out of the river or creek when analysis was begun. As a precaution against unforseen delays, all samples for nitrogen analysis were immediately fixed with mercury. All samples that could not be delivered to the laboratory within two hours were stored in ice. In no case was any sample more than eight hours old upon arrival at the laboratory.

In the May survey, samples for ammonia and Kjeldahl nitrogen analysis were treated with alkaline sodium thiosulfate to decompose the mercury-ammonium complex. In the September survey, they were treated with alkaline potassium iodide to decompose the complex.

Water Analysis

Suspended Solids - Suspended solids were determined by the glass-fiber filtration/gravimetric method (104°C) outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 224-C.

Total Dissolved Solids - Total dissolved solids were determined by .45 micron membrane filtration (104 °C) outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 224-E.

Total Organic Carbon (TOC) - Total organic carbon values were determined by the combustion/infrared method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 138-A.

Chemical Oxygen Demand - Chemical oxygen demand values were determined by the dichromate reflux method outlined in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, Method No. 220.

Kjeldahl Nitrogen - Kjeldahl nitrogen values were determined by the digestion/distillation/titration method outlined in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, Method No. 135.

Ammonia Nitrogen - Ammonia nitrogen values in May were determined by the distillation/titration method outlined in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, Method No. 132-A. In September they were determined with an Orion Model 95-10 ammonia electrode.

Nitrate Nitrogen - Nitrate nitrogen values were determined by the brucine sulfate method outlined in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, Method No. 213-C.

Nitrite Nitrogen - Nitrite nitrogen values were determined by the diazotization method outlined in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, Method No. 134.

Total Phosphorus - Total phosphorus values were determined by persulfate digestion and the single reagent method outlined in *Methods for Chemical Analysis of Water and Wastes*, 1971, page 235.

Total Dissolved Phosphorus - Total dissolved phosphorus values were determined by filtration, persulfate digestion, and the single reagent method outlined in *Methods for Chemical Analysis of Water and Wastes*, 1971, page 235.

Biochemical Oxygen Demand-Curve (Ambient-14°C) - BOD values were determined by the multiple dilution technique outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 219. Dissolved oxygen measurements were made by the membrane electrode technique. All samples were incubated in darkness.

Biochemical Oxygen Demand-Curve (20°C) - BOD values were determined by the multiple dilution technique outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 219. Dissolved oxygen measurements were made by the membrane electrode technique. All samples were incubated in darkness.

Fecal Coliform Bacteria - Fecal coliform bacteria were determined by membrane filtration/24-hour incubation, as outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 408B.

Sediment Analysis

Sample Pretreatment - Large stones were removed and each sample was homogenized in a blender before weighing out individual samples for testing.

Dry Solids - Dry solids were determined at 104°C after 24 hours, as outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 220.

Chemical Oxygen Demand - Chemical oxygen demand values were determined by the dichromate reflux method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 220.

Phosphorus, Total - Total phosphorus values were determined by persulfate digestion and the single reagent method outlined in Methods for Chemical Analysis of Water and Wastes, 1971, page 235.

Phosphorus, Acid Hydrolyzable - Acid hydrolyzable phosphorus was determined by sulfuric acid hydrolysis and the single reagent method outlined in Methods for Chemical Analysis of Water and Wastes, 1971, page 235.

Kjeldahl Nitrogen - Kjeldahl nitrogen values were determined by the digestion/distillation/titration method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 135.

Ammonia Nitrogen - Ammonia nitrogen values were determined by the distillation/titration method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 132-A.

Nitrate Nitrogen - Nitrate nitrogen values were determined by the brucine sulfate method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 213-C.

Nitrite Nitrogen - Nitrite nitrogen values were determined by the diazotization method outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 134.

Oils and Grease - Oils and grease values were determined by freon/soxlet extraction of the dry solids outlined in FWQA, Methods of Chemical Analysis, 1969.

Cyanide, Total - Total cyanide value was determined by distillation/colorimetry as outlined in Standard Methods for the Examination of Water and Wastewater, 13th Edition, Method No. 207-A,C.

10. RECOMMENDATIONS

1. Wasteloads in the Maumee River estuary cannot be rationally allocated until its hydraulics and sediment dynamics are thoroughly understood. We recommend that a two-year research program be instituted as soon as possible to answer these needs. For the present, one cannot even specify the hydrological conditions to be used in designing the allocation. The droughtflow of the Maumee River at Waterville, which is currently being used as the design condition, is irrelevant to the causes of poorest water quality in this, the most populous, most industrialized part of the largest tributary to the Great Lakes, the largest estuary in Lake Erie, the largest river in northern Ohio.

2. The estuary is not a riffle and should not be sampled as though it were. Sampling schemes must pay due attention to three major features of estuarine behavior: stratification, flow reversals, and irregular times of passage. Virtually all the data which have been amassed by the routine monitoring programs in the Toledo area should be discounted for this reason alone. All these programs must revise their sampling techniques; they should also pay more attention to sample preservation, sample storage, and quality control in the analytical laboratory. The continuous monitors for pH, DO, temperature, and conductivity should be more frequently calibrated and better maintained.

3. Insofar as current policies and practices for developing wasteload allocations fail to distinguish estuaries from free-flowing streams, they must be changed. The 7-day, 10-year low flow of the Maumee at Waterville has nothing to do with water quality in the estuary; in fact, the estuary is cleanest when it contains least riverwater. Poorest water quality in the estuary is likely to occur when the estuary is low, warm, stagnant, and filled with riverwater; it will not occur when the

estuary receives large volumes of backflow of cleaner water from Lake Erie. The research program suggested in Recommendation #1 must develop the exact specifications of the estuarine condition to be used in waste-load allocation.

4. Water-quality standards for the lower Maumee and its tributaries must be clarified and made much more precise. The "ammonia" standard should be reworded and redefined to stop the confusion between ammonium and ammonia. The several monitoring programs in greater Toledo should be coordinated; they might profitably join forces to determine exactly when and where the water-quality standards are violated.

5. The principal violations of the numerical water-quality standards are low DO, high fecal coliform bacteria, and warm water near Toledo Edison's Acme powerplant. The non-numerical standards are violated by the dribbling (often gushing) sewers, which are responsible for much of the floating filth and for the bubbling sludge beds in the river. Because the poor sewers are partly or wholly responsible for many of the worst violations of water-quality standards, sewer repair should be undertaken without delay. Improvements in Toledo's three dozen sewer regulators would pay handsome dividends in higher water quality. Until the sewers are upgraded, the lower Maumee will often violate the DO and bacterial standards, even if Toledo's sewage-treatment plant is re-engineered to discharge distilled water: The waste must get to the plant through the sewers if it is to be treated. The water around the Acme powerplant is not warm enough to cause any harm by itself; but Acme's warm outfall further depresses the estuary's DO by raising the water temperature a few degrees. We recommend that this large, warm discharge be carefully controlled when the river's DO is low; we also recommend that the DO standard of 5 mg/l in the vicinity of the Acme outfall be reconsidered.

6. The performance of Toledo's sewage-treatment plant is erratic; though its discharge is often good, there are times when it is deplorable. Its operation and maintenance should be improved immediately; if these improvements are not sufficient, the plant must be structurally modified.

7. Much more attention must be paid to area sources (especially landwash) in the drainage area above Waterville. All the point sources in the basin are dwarfed by the river's flowing loads when it is in spate. The point sources do not begin to account for the river's contents, or for the great majority of the material which the river transports into Lake Erie. The lower Maumee would be muddy, loaded with salts, solids, BOD, nitrogen, and phosphorus even if all the cities and industries in the basin were to be wiped off the map. Better soil conservation and more efficient use of agricultural chemicals would help; but it is well to remember that the river was muddy, bordered by malarial swamps, and obstructed by bars of sand, clay, and gravel long before the basin was settled in the nineteenth century. The size of the wasteload from area sources and rural landwash must be borne in mind when developing wasteload allocations for the Toledo area: The estuary may store the accumulated wastes of the entire basin for long intervals.

8. The level of Lake Erie has been high for the last several years, and the high water has affected the Maumee estuary. It is impossible to collect the fundamental data for wasteload allocations in the estuary until the lake level falls again. There is, however, much that can be done meanwhile: Attend to the sewers, the operation of the waste-treatment plants, the monitoring programs, and the scanty knowledge of the estuary's hydraulics and sediment dynamics.

9. Only one set of water-quality standards has been promulgated for all the waters in the Toledo area, even though these waters are

diverse in every way: in quality, quantity, hydrology, and in actual uses. Surely more should be expected of the capacious Maumee estuary than of little Otter Creek, whose flow is largely derived from the effluents of petroleum refineries; and surely the upper reaches of Swan Creek (which are little more than stagnant mosquito pools in dry summers) could never attain the quality that can be expected of the estuary, which usually contains large volumes of clean water from Lake Erie. The current standards should be revised to reflect the diversity of the various watercourses in the area, and of their varying potential for improvement.

10. The situation we have described in the waters around Toledo is not unique: Toledo's problems are paralleled in many other cities which discharge into hydraulically complex waters. Greater attention to these complexities elsewhere will lighten the tasks to be done in the lower Maumee by establishing valuable precedents and by improving methods, policies, and procedures for standard-setting and wasteload allocation. Although Toledo's problems are largely local, their implications are national. What is learned about the Maumee estuary will be valuable in the Sandusky, Portage, and even the Cuyahoga estuaries; what is learned about the St. Louis River and Duluth, or about the Fox River and Green Bay, will be useful to policy-makers and pollution-control specialists in Toledo, Columbus, Chicago, and Washington.

APPENDIX 1

Dissolved Oxygen, Temperature, and Conductivity in the Maumee River Estuary, 21-25 September 1974

DO, temperature, and conductivity values are tabled, in that order, at each of ten transects. These values demonstrate stratification (both horizontal and vertical), and provide evidence of DO and temperature violations.

The DO/temperature meter (YSI model 54) was fully calibrated in the laboratory several times during the survey, and was recalibrated against Winkler titrations in the field several times each day; it held calibration extremely well, and never required more than 0.2 mg/l adjustment. The conductivity meter (YSI model 51) was fully calibrated in the laboratory several times during the survey. Our pH meter would not hold calibration; we have discarded all pH data from the field survey. Otherwise, all the field data -- we believe -- are entirely reliable.

The data are tabled in vertical groups of two or three readings. The first (top) reading is always DO, in mg/l; the second is temperature, in degrees Celsius; the third is specific conductance, in micromhos, adjusted to 25°C. Spatial relationships are generally preserved in the tables. Water depths are given next to each group of readings. Variations in stage (due to lake effects) and an unstable bottom (due to moving bars of mud and sand) account for differences in water depth from day to day -- or even from minute to minute. Diurnal variation is confounded somewhat by lake effects, but DO variation was always less than one mg/l at any given sampling point. Note that DO is always greater than 5 mg/l above the Anthony Wayne Bridge (RM 5.4), and is frequently below 5 from Wayne Bridge to the mouth of the river.

Figure 7-18 depicts the transects we used.

Perrysburg Bridge. Six piers in water, consecutively numbered from east to west. RM 14.1. 21 September 1974, 00:27. DO, temperature, and conductivity.

	Pier #		
	#5	#3	#1
depth (ft)	5'	7'	4.5'
2	11.2 mg/l 19.2°C @2' 740 micromho	11.4 19.2 @2' 740	11.2 19.0 @2' 730
4	11.2 19.2 @4' 740	11.6 19.4 @4' 740	11.8 19.0 @4' 730

Highway 80/90 Bridge. Six piers in water, consecutively numbered from east to west. RM 11.4. 21 September 1974, 01:30. DO, temperature, and conductivity.

	Pier #					
	#6	#5	#4	#3	#2	#1
depth (ft)	8'	10'	10'	10'	10'	9.5'
2	7.8 mg/l 19.3°C @2' 670 micromho	7.6 19.3 @2' 660	7.6 19.2 @2' 620	7.6 19.2 @2' 680	7.7 19.1 @2' 670	7.6 19.0 @2' 680
4						
	7.8 19.5 @5' 650	7.7 19.4 @5' 610	7.8 19.4 @5' 630	7.7 19.3 @5' 600	7.7 19.3 @5' 630	7.7 19.2 @5' 650
6						
8	7.9 19.6 @8' 630	7.8 19.5 @8' 630	7.8 19.5 @8' 650	7.7 19.5 @8' 660	7.9 19.3 @8' 640	7.9 19.2 @8' 650

Highway 80/90 Bridge. 21 September 1974, 14:15. DO, temperature, and conductivity. Rain squall began at 14:20, lasted half an hour.

	Pier #	
	#4	#1
depth(ft)	9'	9'
2	7.2 mg/l 19.6°C @2' 680 micromho	7.6 19.7 @2' 700
4		
6		
	7.2 19.0 @7' 680	7.5 19.3 @7' 690
8		

DiSalle Bridge. Nine piers in water, consecutively numbered from east to west. RM 6.9. 21 September 1974, 04:15. DO, temperature, and conductivity.

		Pier #	
	#7	#4	#1
depth(ft)	12'	15'	13'
2	5.7 mg/l 19.3°C @3" 580 micromho		5.7 19.3 @3' 540
4		5.9 19.3 @4' 580	
6	5.9 19.4 @6' 580		5.8 19.5 @6' 520
8		6.1 19.5 @8' 550	
10	6.0 19.5 @9' 590		5.9 19.6 @9' 520
12		6.2 19.5 @12' 550	
14			

DiSalle Bridge. 22 September 1974, 13:10. DO, temperature, and conductivity.

	Pier #		
	#7	#5	#2
depth(ft)	10'	13'	13'
2	6.4 mg/l 18.3°C @2' 610 micromho		
4		6.6 18.4 @3' 620	7.0 18.2 @3' 620
6			
8	6.5 18.4 @7' 620		
10		6.7 18.4 @10' 600	7.0 18.3 @10' 620
12			

DiSalle Bridge. 23 September 1974, 08:45. DO, temperature, and conductivity.

	Pier #		
	#7	#4	#2
depth(ft)	10'	17'	14'
2	6.0 mg/l 17.8°C @2' 650 micromho	6.4 17.5 @2' 630	6.9 17.5 @2' 650
4			
6			
8	6.3 17.8 @7' 590	6.7 17.6 @8' 620	7.0 17.5 @8' 590
10			
12			7.0 17.5 @12' 520
14			
16		7.0 17.7 @15' 590	

Conductivities at Pier #4 were remeasured at 09:20, as follows

@ 2'	630 micromho
@ 8'	580 micromho
@ 15'	570 micromho

DiSalle Bridge. 23 September 1974, 10:15. DO, temperature, and conductivity.

	Pier #	
depth(ft)	#4 18'	#2 12'
2	6.7 mg/l 17.4°C @2' 630 micromho	6.9 17.1 @2' 650
4		
6		
8	6.8 17.5 @8' 620	
10		
12		7.0 17.4 @11' 600
14		
16	6.9 17.5 @15' 620	

DiSalle Bridge. 23 September 1974, 12:40. DO, temperature, and conductivity.

		Pier #	
	#7	#4	#2
depth(ft)	14'	18'	14'
2	5.5 mg/1 18.7°C @2' 640 micromho	5.6 18.8 @2' 650	5.6 18.9 @2' 650
4			
6			
8	5.5 18.6 @7' 630	5.4 18.6 @8' 580	5.8 18.2 @8' 600
10			
12			6.3 18.0 @11' 580
14			
16		6.5 17.9 @15' 600	

DiSalle Bridge. 24 September 1974, 15:10. DO, temperature, and conductivity.

	Pier #		
	#7	#4	#2
depth(ft)	12'	18'	13'
2	6.0 mg/l 18.2°C @2' 670 micromho	6.0 18.0 @2' 670	5.7 18.0 @2' 670
4			
6			
8	6.0 18.0 @7' 640	6.0 18.0 @8' 670	5.8 17.5 @8' 670
10			
12			6.0 17.5 @11' 660
14			
16		6.0 17.8 @15' 660	

Anthony Wayne Bridge. No piers in water. Flagged white buoy approx. 50' from west bank. Red lights on bridge span mark limits of navigation channel, which comes close to the east bank. RM 5.4.
20 September 1974, 22:00. DO and temperature.

	White Buoy		West Red Light		East Red Light
depth(ft)	17.5'		25'		30'
2	4.7 mg/l 20.3°C @2'				
4	5.0 21.4 @4'				
			5.5 21.5 @5'	5.4 19.3 @5'	5.9 21 @5'
6	5.1 21.4 @6'				
8	5.0 21.5 @8'				
10	4.3 21.3 @10'		5.0 21.5@10'	4.7 21.5@10'	4.8 21 @10'
12					
14					
	3.7 20.7 @15'	drifting into muck	4.6 20.8@15'	4.8 20.8@15'	5.0 20.5 @15'
16					
18					
20			4.8 20.2@20'	4.9 20.3@20'	5.0 20.2 @20'
25					5.0 20.0 @25'

Anthony Wayne Bridge. 21 September 1974, 05:00. DO, temperature, and conductivity.

	15' West of Channel	Midchannel	50' East of Channel
depth(ft)	13'	32'	26'
2			
	4.7 mg/l		
	21.2°C @3'		
4			
			4.7 mg/l
			21.5°C @5'
6			
			500 micromho
		4.9	
8		21.0 @8'	
		550	
	4.7		
10	21.0 @10'		
			5.0
12			21.3 @12'
			520
14			
		5.2	
16		20.8 @16'	
		560	
18			
			5.2
20			20.8 @20'
			530
22			
		5.3	
24		20.5 @24'	
		570	

Anthony Wayne Bridge. 22 September 1974, 14:00. DO and temperature.

depth(ft)	White Buoy 18'	Midchannel 32'	35' from East Bank 28'
5	5.2 mg/l 19.6°C @5'	5.5 19.4 @5'	5.5 19.3 @5'
10			
15	5.4 19.5 @15'		
20			
25		5.6 19.3 @25'	5.5 19.2 @25'

Anthony Wayne Bridge. 24 September 1974, 14:00. DO, temperature, and conductivity.

	White Buoy	Midchannel	15' from East Bank
depth(ft)	18'	31'	24'
2	5.1 mg/l 18.4°C @2' 650 micromho	5.2 18.6 @2' 630	5.5 18.7 @2' 650
4			
6			
8			
10	5.1 18.4 @10' 580	5.2 18.5 @10' 630	5.7 18.6 @10' 630
12			
14			
16	5.0 18.5 @15' 600		
18			
20			5.7 18.6 @20' 620
22			
24			
26		5.6 18.3 @25' 640	

Cherry Street Bridge. Seven piers in water, numbered consecutively from east to west. Lift span between piers 5 and 6. RM 4.6. 20 September 1974, 21:25. DO and temperature.

	Pier #		
	#7	#6	#1
depth(ft)	25'	31'	12'
			5.1 mg/l 23°C @2'
			5.0 22.5 @4'
5	4.6 22 @5'	4.9 23 @5'	
			4.5 21.5 @6'
			4.4 21.5 @8'
10	4.4 21 @10'	4.9 21 @10'	4.3 21 @10'
			4.2 21 @12'
15	4.5 21 @15'	4.7 20.5 @15'	
20	4.6 20.5 @20'	4.6 20.3 @20'	

Cherry Street Bridge. DO, temperature, and conductivity.
21 September 1974, 05:45.

	Pier #		
	#7	#6	#2
depth(ft)	25'	27.5'	18'
2			
4	4.5 mg/l 21.5°C @5' 540 micromho	4.6 20 @5' 550	4.4 21 @5'
6			
8			
10			4.4 20 @10'
12	4.3 21 @12' 550	5.0 20.5 @12' 550	
14			4.6 20 @15'
16			
18			
20	4.7 20 @20' 570	4.9 20 @20' 530	

Cherry Street Bridge. DO, temperature, and conductivity.
23 September 1974, 11:15.

	Pier #		
	#6	#4	#2
depth(ft)	28'	24'	14'
2	4.3 mg/l 19.5°C @2' 610 micromho	4.4 19.5 @2' 610	4.0 19.5 @2' 610
4			
6			
8			
10	4.2 20 @10' 610	4.2 19.5 @10' 610	4.1 19.5 @10' 600
12			
14			
16			
18			
20	4.5 20 @20' 610	4.1 19.5 @20' 610	

Cherry Street Bridge. DO, temperature, and conductivity.
24 September 1974, 13:30.

	Pier #		
depth(ft)	#7 24'	#5 25'	#2 17'
2	4.9 mg/l 18.6°C @2' 630 micromho	4.7 18.9 @2' 630	4.9 19.0 @2' 630
4			
6			
8			4.7 19.0 @8' 620
10	4.9 18.8 @10' 630	4.5 18.9 @10' 620	
12			
14			
16			4.7 19.0 @15' 620
18			
20	5.0 18.8 @20' 620	4.5 18.9 @20' 580	

Cherry Street Bridge. DO, temperature, and conductivity.
24 September 1974, 22:12.

	Pier #		
depth(ft)	#7 23'	#5 28'	#2 19'
2	4.6 mg/l 18.8°C @2' 650 micromho	4.6 18.7 @2' 630	4.8 19.0 @2' 630
4			
6			
8			4.7 19.1 @8' 610
10	4.7 18.9 @10' 610	4.9 18.9 @10' 600	
12			
14			
16			4.7 19.0 @15' 610
18			
20	4.4 18.8 @20' 620	5.1 18.8 @20' 610	

Craig Bridge. Five piers in water, but pier nearest east bank in less than three feet of water. Piers consecutively numbered from east to west. Lift span between piers 4 and 5. RM 3.6. 24 September 1974, 12:10. DO, temperature, and conductivity.

		Pier #	
depth(ft)	#5 27'	#3 18'	#2 9.5'
1			
	4.4 mg/1	4.2	4.1
	22°C @2'	22 @2'	23 @2'
4	680 micromho	670	700
7		4.0	3.9
		20.7 @8'	21.2 @7'
	4.7	610	650
10	21.4 @10'		
	650		
13			
		3.6	
		19.9 @14'	
16		620	
19			
21			
24			
	3.7		
	19.7 @25'		
27	630		

Craig Bridge. 25 September 1974, 02:40. DO, temperature, and conductivity.

	Pier #		
	#5	#3	#2
depth(ft)	25'	21'	10'
2	4.6 mg/l 19.1°C @2' 630 micromho	3.5 19.4 @2' 610	3.3 19.5 @2' 600
4			
6			
8		3.7 19.8 @8' 600	3.1 19.4 @7' 570
10	4.2 19.3 @10' 600		
12			
14		3.7 19.5 @14' 580	
16			
18			
20	4.2 19.4 @20' 590		
22			

Toledo Terminal RR Bridge. Six piers in water, consecutively numbered from east to west. RM 1.3. 25 September 1974, 08:10. DO, temperature, and conductivity.

		Pier #	
depth(ft)	#5 6'	#3 25'	#1 17'
2	5.0 mg/l 20.0°C @2' 570 micromho	4.9 19.9 @2' 550	5.0 19.9 @2' 550
4	5.0 20.2 @4' 550		
6			
8			
10		5.0 20.2 @10' 510	5.0 19.9 @10' 510
12			
14			
16			5.2 19.5 @15' 500
18			
20		5.1 20.0 @20' 510	
22			

Mouth of Coast Guard Slip, mid-channel. RM 0. 25 September 1974, 08:45. DO, temperature, and conductivity.

4.4 mg/l
19.3°C @2'
620 micromho

4.4
19.3 @10'
580

4.4
19.1 @15'
No conductivity reading taken

Mouth. The transect is a straight line extending from the Coast Guard slip (on the west bank), through the navigation channel between buoys #49 and #50, to the tip of the coal docks (just east of the mouth of Duck Creek). The three sampling points on this transect are: (1) white buoy (unnumbered), 150' east of the Coast Guard slip; (2) midway between buoys #49 and #50; and (3) six feet from the tip of the coal docks. These three stations are called "west", "mid", and "east", respectively. RM 0. 22 September 1974, 16:15. DO, temperature, and conductivity.

	West	Mid
depth(ft)	10'	32'
3	5.4 mg/l 19.5°C @3' 420 micromho	
6		5.2 20 @5' 410
9	4.9 19.7 @7' 410	
12		
15		5.5 19.7 @15' 410
18		
24		
27		6.3 19.0 @25' 410

USGS measured the instantaneous velocity as 0.4 fps. At 7' depth, the West sample was much more turbid (to the unaided eye) than at 3'.

Mouth. 23 September 1974, 15:11. DO, temperature, and conductivity.

	Mid
depth(ft)	32'
3	4.8 mg/l 19.9°C @2' 490 micromho
6	
9	
12	
15	6.8 18.0 @16' 400
18	
24	7.7 17.4 @25' 380
27	

Mouth. 24 September 1974, 11:30. DO, temperature, and conductivity.

	West	Mid	East
depth(ft)	8'	32'	27'
3	4.7 mg/l 19.0°C @2' 480 micromho	5.7 18.1 @2' 430	5.5 18.0 @2' 420
6	4.6 18.9 @6' 470		
9			
12			
15		5.8 18.1 @15' 400	
18			
21			6.7 17.3 @20' 360
24			
27		6.7 17.6 @25' 360	

At 6' depth, the west sample was much more turbid (to the unaided eye) than at 2'.

Mouth. 25 September 1974, 09:25. DO, temperature, and conductivity.

	West	Mid	East
depth(ft)	8'	30'	27'
3	5.2 mg/l 19.5°C @2' 540 micromho	5.7 19.3 @2' 500	5.9 18.0 @2' 490
6	4.8 19.6 @6' 580		
9			
12			
15		5.9 19.3 @15' 480	
18			
21			6.2 18.0 @20' 410
24			
27		6.4 18.9 @25' 450	

Dike #13. Quadrilateral dredge-dump island at SW end of Maumee Bay. All samples taken in navigation channel, midway between buoys #41 and #42 (at SE tip of island, 1.5 miles from mouth of Maumee River).

Dike #13. 23 September 1974, 15:27. DO, temperature, and Conductivity.

depth = 34'

8.1 mg/l
18.5°C @2'
400 micromho

9.7
16.8 @17'
350

10.2
16.0 @25'
275

Clearer at 25' than in upper strata

Dike #13. 24 September 1974, 11:10. DO, temperature, and conductivity.

depth = 36'

9.6 mg/l
15.5 °C @2'
250 micromho

10.2
15.3 @18'
255

All strata less turbid than yesterday

10.2
15.2 @28'
230

Dike #13. 25 September 1974, 07:47. DO, temperature, and conductivity.

depth = 32'

7.9 mg/l
16.3°C @18'
320 micromho

The channel bottom is soft goo. The boat anchor bites, but slides

9.0
15.2 @18'
295

10.0
15.9 @28'
280

APPENDIX 2

Miscellaneous Observations on the Maumee River and Nearby Streams

Table A2-1 presents flow measurements (discharge and mean velocity) kindly made by the USGS during our September survey.

TABLE A2-1.

USGS FLOW MEASUREMENTS, 20-23 SEPTEMBER 1974

Location	Date	Time	Mean Velocity (fps)	Discharge (cfs)
Maumee River at Cherry Street Bridge	9-20-74	18:30	0.08	-1460*
	9-21-74	15:00	0.43	7240*
	9-22-74	13:30	0.31	5160*
Maumee River at Perrysburg Holland Road Bridge	9-20-74	15:30	0.21	692*
	9-21-74	12:00	0.04	107*
Maumee River at Waterville	9-21-74	09:30	1.02	441
Swan Creek above Byrne Road	9-22-74	11:15	0.46	3.07
Swan Creek at Highland Park	9-22-74	09:30	0.18	3.95
Ottawa River at Ottawa Park Golf Course	9-23-74	09:00	0.78	3.27

*These measurements affected by seiche action from Lake Erie.

Very little rain fell during late September and early October, nor had there been much rain for several months: Toledo had a very dry summer. The total September rainfall at Toledo Express Airport was 1.41 inches, and much of that came in one shower on the 10th. The USGS flow measurements in the free-flowing portion of Swan Creek and the Ottawa River (also called Tenmile Creek, especially in its non-estuarine reaches) may therefore be taken as representative of their flows in late summer and early autumn; flows were gaged just above their estuaries.

Tables A2-2 and A2-3 summarize our analyses of Swan Creek and Tenmile Creek/Ottawa River. All samples of the non-estuarine waters were taken within the space of a few hours, since the creeks were in steady state. The estuarine reaches were sampled much later, to allow for travel time; samples were collected during a pronounced estuarine flush. Times of travel are affected by more than lake effects: Low dams (e.g., in Swan Creek at South Avenue) further increase detention times.

Swan Creek at Scott Road is near the top of the drainage basin. A golf course is just upstream, and the small Swanton STP is just above the golf course. The streambed was soft, bubbling, black, anaerobic muck which emitted a powerful odor of sulfides when disturbed. Although the water was stagnant (there was no perceptible flow on 27-28 September, as gaged by floating oranges), neither DO nor temperature showed horizontal stratification. The water was swarming with mosquitos, flies, and larvae, and was surfaced with floating patches of green scum. As table A2-2 shows, the water violated WQS for DO, "ammonia", and bacteria. BOD, COD, total carbon, total nitrogen, and total phosphorus were the highest we observed anywhere in our September survey. None of this pollution can be blamed on Toledo or on heavy industry. The infamous Black Swamp of early nineteenth-century accounts may have resembled this (see section 2 of the main report). A Kemmerer sampler was used.

Swan Creek just upstream of the Route 20A Bridge in Monclova was nearly dry and almost completely dammed by mud and debris under the

TABLE A2-2. SWAN CREEK AT SCOTT ROAD, ROUTE 20A, BYRNE ROAD, AND MONROE STREET, 27 SEPTEMBER - 10 OCTOBER 1974

Test Parameter	Scott Rd.[1]	Route 20A[2]	Byrne Rd.[3]	Monroe St.
Date	9/27/74	9/27/74	9/27/74	10/8/74
Time	15:00	15:30	16:30	10:00
Stream depth (ft)	2.5	<1.	<1.	9
Sample depth (ft)	1.5	surface	surface	5
DO (mg/l)	0.3*	5.2	7.8	--
Temperature (°C)	13.2	14.8	16.5	--
Conductivity (micromhos)	850	850	740	--
SS (mg/l)	12	4	4	50
TDS (mg/l)	656	555	531	441
Total C (mg/l)	93	53	50	54
Inorganic C (mg/l)	30	27	25	23
Organic C (mg/l)	63	26	25	31
COD (mg/l)	140	47	23	54
Total N (mg/l)	81.0	1.582	5.153	17.562
Kjeldahl N (mg/l)	49.0	0.99	1.85	16.2
Ammoniacal N (mg/l)	31.9*	0.16	1.71*	0.75
NO_3 N (mg/l)	0.09	0.42	1.30	0.56
NO_2 N (mg/l)	0.010	0.012	0.293	0.052
Total P (mg/l)	12.3	1.18	1.52	0.36
Dissolved P (mg/l)	10.4	1.12	1.45	0.18
Fecal Coliform Bacteria (organisms/100 ml)	8,900*	18	1,700*	690*
20°-BOD_1	3	<1	<1	2
20°-BOD_2	5	1	<1	4
20°-BOD_3	8	2	1	6
20°-BOD_4	13	2	1	6
20°-BOD_5	16	2	2	--
20°-BOD_6	--	--	--	7
20°-BOD_{10}	34	3	7	9
20°-BOD_{20}	102	5	7	10
20°-BOD_{30}	114	7	7	13

---

[1] On 28 September, 14:05, DO was 1.2*, temperature was 17.2°, conductivity was 830.

[2] On 28 September, 14:30, DO was 4.5*, temperature was 16.5°, conductivity was 860.

[3] On 28 September, 15:30, DO was 7.1, temperature was 17.0°, conductivity was 700. An oil slick extended several yards above and below the sampling point.

*Violates water-quality standards.

TABLE A2-3. TENMILE CREEK/OTTAWA RIVER AT SILICA DRIVE, MONROE STREET, STICKNEY AVENUE, AND SUMMIT STREET, 27 SEPTEMBER - 15 OCTOBER 1974

Test Parameter	Silica Dr.	Monroe St.	Stickney Ave.	Summit St.
Date	9/27/74	9/27/74	10/15/74	10/15/74
Time	18:15	18:45	11:00	11:40
Stream depth (ft)	< 1	< 1	--	--
Sample depth (ft)	surface	surface	5	5
DO (mg/l)	10	7.9	--	--
Temperature (°C)	17	16	--	--
Conductivity (micromhos)	1,070	800	--	--
SS (mg/l)	1	12	32	74
TDS (mg/l)	978	554	502	320
Total C (mg/l)	38	42	77	43
Inorganic C (mg/l)	21	19	27	16
Organic C (mg/l)	17	23	50	27
COD (mg/l)	23	31	113	182
Total N (mg/l)	0.798	1.538	20.52	2.464
Kjeldahl N (mg/l)	0.40	0.54	13.0	2.17
Ammoniacal N (mg/l)	0.20	0.19	7.42*	0.12
NO_3 N (mg/l)	0.19	0.75	0.09	0.15
NO_2 N (mg/l)	0.008	0.058	0.010	0.024
Total P (mg/l)	0.11	0.82	3.15	0.36
Dissolved P (mg/l)	0.09	0.70	2.55	0.11
Fecal Coliform Bacteria (organisms/100 ml)	93	46	276,000*	8
$20°\text{-BOD}_1$	1	1	10	1
$20°\text{-BOD}_2$	1	3	13	3
$20°\text{-BOD}_3$	1	3	14	5
$20°\text{-BOD}_4$	2	4	17	6
$20°\text{-BOD}_5$	2	5	--	--
$20°\text{-BOD}_6$	--	--	23	8
$20°\text{-BOD}_{10}$	2	7	28	9
$20°\text{-BOD}_{20}$	4	10	48	11
$20°\text{-BOD}_{30}$	5	10	48	12

---

*Violates water-quality standards.

bridge. The flow was a trickle, and was accompanied by a flowing sludge bank. The streambed was soft ooze. The DO standard was violated on both 27 and 28 September, though the violations were far less severe than at Scott Road, which is several miles upstream. The sample for laboratory analysis was taken a few yards upstream of the bridge by carefully filling the sample-collection bottle with beakers of creekwater; this collection method had to be used whenever the stream was less than 2 feet deep. We approached the sample point from the downstream direction and took elaborate precautions to avoid roiling the streambed. The sample was collected midstream where the current was least sluggish.

Swan Creek at Byrne Road Bridge was (as at Route 20A Bridge) too shallow to sample. Our sampling point was 150 feet upstream of the bridge. The streambed was much coarser than at either Scott Road or Route 20A and (for the first time) it was firm. It was not anaerobic, and neither bubbled nor smelled when disturbed. Although the streambed and the water were much pleasanter to behold than at Route 20A, the water violated both the "ammonia" and bacterial standards. The streamflow was approximately 3 cfs, the velocity about 0.5 fps. The velocity and the clean streambed must account for the improved DO, because BOD was what it had been at Route 20A (as were COD and organic carbon), and reduced forms of nitrogen were much higher.

Below Byrne Road Swan Creek leaves the suburbs and flows through one of Toledo's oldest sections; seiche effects from the Maumee estuary and Lake Erie begin a few miles below Byrne Road. By the time Swan Creek has reached its mouth (at Monroe Street), it is nearly 10 ft deep and 100 ft wide; most of this volume is stored water: This is a small estuary. There are several sewer outfalls and regulators in lower Swan Creek, and malfunctioning regulators (recall that there had been almost no rain for several months) must be held accountable for the high bacterial concentration at Monroe Street. The water does not tell the whole story: The sediments at the mouth of Swan Creek (see section 8 of the main report) are extremely polluted. The high SS values in the Monroe Street sample may be attributed to scouring of the sediments by the flushing currents; the very high concentration of Kjeldahl nitrogen was no doubt largely associated with the scoured sediments. The low TDS values at Monroe Street must be attributed to backflow from the Maumee estuary. One of the lessons to be derived from our survey is this: Although dilution may not be a solution to pollution, it certainly improves water quality. Were it not for estuarine dilution and sewer outfalls, the water at Monroe Street could scarcely be much better than it had been at Scott Road: There's nothing like water to improve water quality.

This lesson was reinforced by our survey of Tenmile Creek. The first point we had picked for sampling was Lathrop Road, upstream of Berkey, near the top of the drainage basin. The stream was dry, though the streambed was still slightly moist here and there. As for aquatic life -- we saw not so much as a sludge worm or mosquito larva. Nothing daunted, we traveled "downstream" (if a dry streambed may be said to have a flow direction) to Sylvania-Metamora Road, but found nothing but parched mud for our trouble. Leaving the rural portion of the basin, we next went to Silica Drive, in suburban Sylvania, and at last we found water, but water of very high conductivity, owing to the discharge from a quarry. The water met all standards, and we found both algae and rooted plants growing on the rocky bottom.

Our next stop was Monroe Street, where Tenmile Creek is flowing through Ottawa Park and Jermain Park; the upstream drainage area is still largely suburban and non-industrial. The creek was in riffle, with quantities of slime and algae growing on the submerged rocks. The air was thick with mosquitoes, and one could smell the nearby Monroe Street sewer; we took our sample downstream from Monroe Street. Notice that conductivity and TDS had dropped to normal, and that the water met all WQS. Total nitrogen, total phosphorus, and suspended solids were far higher than they had been at Silica Drive.

Several miles below Monroe Street the creek becomes estuarine; the Ottawa River estuary is very large in relation to the size of Tenmile Creek. At Stickney Avenue the estuary is quite large, and there are large industrial parks and several sewer outfalls above it. These wastes have their effects on the water, whose TDS was only about 10% lower than it was at Monroe Street; hence, there could not have been much dilution by backflow from Maumee Bay. The water violated the "ammonia" and bacterial standards. In nearly every respect it was much dirtier than it had been at Monroe Street: Organic carbon, COD, total nitrogen, unoxidized nitrogen, total phosphorus, dissolved phosphorus, bacteria, and every form of BOD were much higher.

At Summit Street, where the estuary becomes very broad, TDS had fallen to about a third of what it had been in Sylvania, and was about a third less than it had been at Stickney Avenue. The drop in TDS may be directly attributed to backflow from Maumee Bay, and the water quality shows it. No standards were violated. SS and COD were higher than at Stickney (perhaps owing to scour by the flushing currents), but in nearly every other respect the water was cleaner. Dilution does help.

The Coast Guard Slip, which connects the lagoon of the Bay View Park Yacht Club with the Maumee River, consistently violated the DO standard (see appendix 1); it also violated the "ammonia" standard. Table A2-4 shows that the water is enriched in phosphorus and nitrogen and high in BOD. There are no sewers or industries to be blamed for

TABLE A2-4. MOUTH OF COAST GUARD SLIP, 25 SEPTEMBER 1974

Date	9/25/74
Time	08:45
Water depth (ft)	17
Sample depth (ft)	10
DO @ 2' (mg/l)	4.4
DO @ 10' (mg/l)	4.4
DO @ 15' (mg/l)	4.4
Temperature @ 2' (°C)	19.3
Temperature @ 10' (°C)	19.3
Temperature @ 15' (°C)	19.1
Conductivity @ 2' (micromhos)	620
Conductivity @ 10' (micromhos)	580
Total P	0.33
Dissolved P	0.17
Total N	6.522
Kjeldahl N	3.11
Ammoniacal N	2.57
NO_3 N	0.69
NO_2 N	0.152
20°-BOD_1	1
20°-BOD_2	2
20°-BOD_3	4
20°-BOD_4	7
20°-BOD_5	10
20°-BOD_{10}	15
20°-BOD_{20}	16
20°-BOD_{30}	17

these conditions, yet something is plainly wrong. When we took our sample, the lake stage had been falling all night, so water from the mooring lagoon had had over twelve hours to drain into the estuary. Perhaps the difficulty may be traced in part to stratified currents of wastes from the STP; perhaps there is faulty waste management at the yacht club or at the several Federal installations. The matter bears looking into.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION V
230 SOUTH DEARBORN STREET
CHICAGO, ILLINOIS 60604

May 30, 1975

DISTRIBUTION NOTICE
GREAT LAKES INITIATIVE CONTRACT PROGRAM

The report "Water Pollution Investigation: Maumee River and Toledo Area" EPA-905/9-74-018 by Enviro-Control, Inc. is provided for your information and use. The report is in fulfillment of EPA Contract Number 68-01-1567.

Region V of the U.S. Environmental Protection Agency has a limited number of copies available for distribution without charge. Additional copies of the report will be available shortly from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Prior reports in this series available from NTIS are as follows:

EPA-905/9-74-001 "Saginaw Bay: An Evaluation of Existing and Historical Conditions", University of Michigan; PB 232440, Paper $4.75, Microfiche $1.45.

EPA-905/9-74-006 "Lower Green Bay: An Evaluation of Existing and Historical Conditions", Wisconsin DNR; PB 236114, Paper $6.75, Microfiche $2.25.

EPA-905/9-74-014 "Water Pollution Investigation: Duluth-Superior Area", Midwest Research Institute; PB 239409, Paper $5.25. Microfiche $2.25.

EPA-905/9-74-011-A "Water Pollution Investigation: Calumet Area of Lake Michigan", Volume 1; IIT Research Institute; PB 239376, Paper $9.25, Microfiche $2.25.

EPA-905/9-74-011-B "Water Pollution Investigation: Calumet Area of Lake Michigan", Volume 2 (Appendices); IIT Research Institute, PB 239377, Paper $7.50, Microfiche $2.25.

EPA-905/9-74-009 "Water Pollution Investigation: Black River of New York", Hydroscience, Inc.

Howard Zar

Howard Zar, Project Officer
Great Lakes Initiative Contracts
Enforcement Branch

Attachment
Distribution List